USC
Space Engineering
Research Center

UNIVERSITY OF SOUTHERN CALIFORNIA
INFORMATION SCIENCES INSTITUTE &
DEPARTMENT OF ASTRONAUTICAL ENGINEERING

BIG IDEAS FOR SPACE:
SPACE ENGINEERING RESEARCH CENTER
INTRODUCTION FOR 2020

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USC Space Engineering Research Center

USC's Space Engineering Research Center: What is it

USC Viterbi School of Engineering — Department of Astronautical Engineering

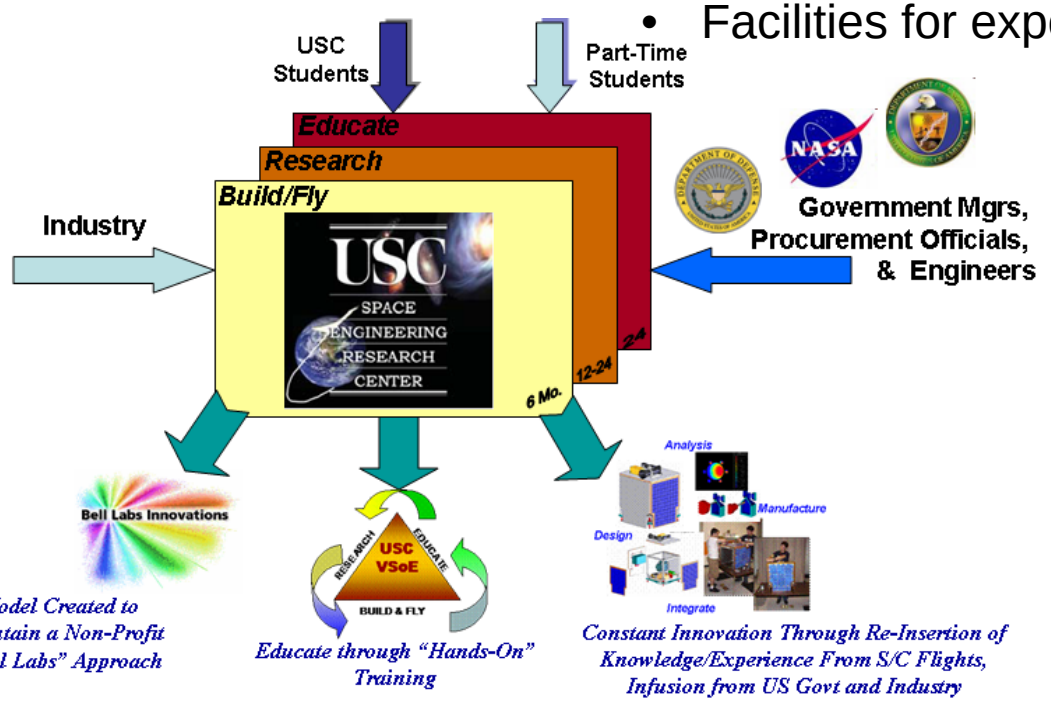
- **Astronautical Engineering (ASTE)**
  - Bachelor of Science
  - Bachelor of Science Minor
  - Master of Science
  - Engineer
  - PhD
  - Graduate Certificate

USC Viterbi School of Engineering — Information Sciences Institute

- **Information Sciences Institute**
  - Part of USC's Viterbi School in Marina del Rey, Arlington, VA, and Waltham, MA
  - >$80M/year from diverse sponsors
  - ~300 people, 2/3rds research staff
  - Facilities for export or restricted research

An academic industry membership run

"Space Engineering Teaching Hospital"



~200 undergrad, graduate and PhD. students involved in all aspects of hands-on space engineering to-date

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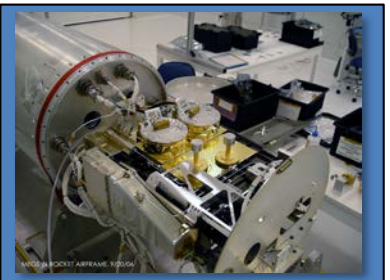
Where is SERC in USC's "Space EcoSystem"

ISI, Arlington VA

ISI, Waltham, MA

Rocket Propulsion Lab

Satellite Ground Communication Station



Space Science Center

Liquid Propulsion Lab

Information Sciences Institute, Marina Del Rey, CA

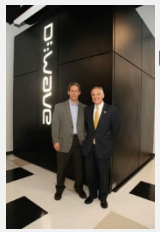
SCCSI
Southern California Commercial Spaceflight Initiative

SoCal Commercial Spaceflight Initiative

USC Main Campus Astronautics Department

USC Polymorphic Robotics Lab

SERC Engineering Offices & Labs (at ISI)



USC-Lockheed Quantum Computing Center & D-Wave One

Institute for Creative Technologies, (Army UARC)

History and how do Student's Participate?

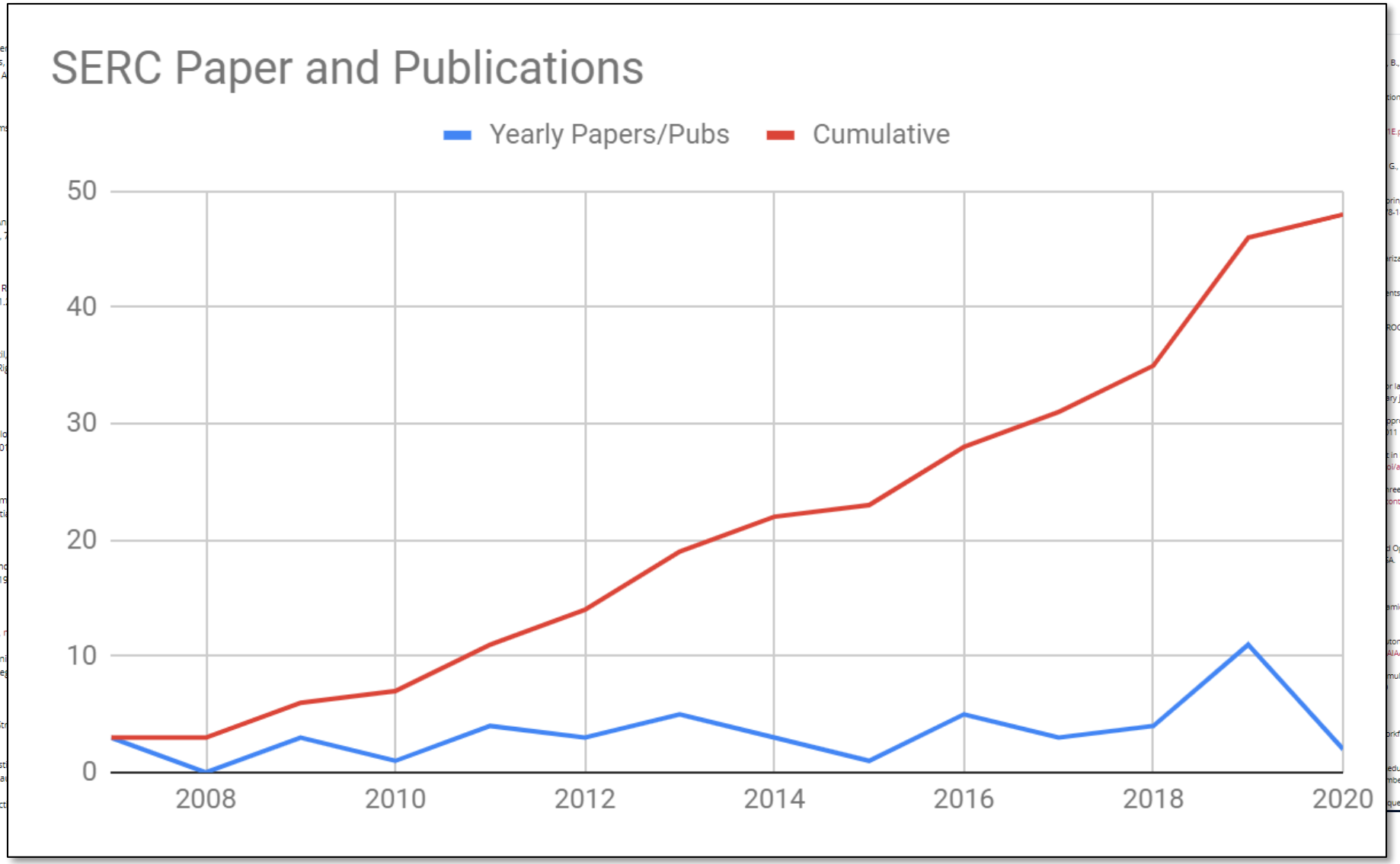
- **History**
  - Work at ISI started in 2006 with US Government and Industry contracts
  - Started as Center in 2007 with ASTE
  - Funding through variety of sources
    - Restricted Gifts
    - USG research contracts and grants
    - Industry research contracts

- **Student Researcher Makeup**
  - High School Students (~4/year)
  - Undergraduates (~15-20/year)
  - Masters Students (~30-40/year)
  - PhD's (~2/year)
  - International Visiting Students (~5/year)

- **Ways to Participate as a Student**
  - Volunteer
  - Directed Research
  - ASTE 291/491 Project Class
  - Paid Projects
  - GRA
- **In Fall 2019, 80 applications for SERC Positions!**

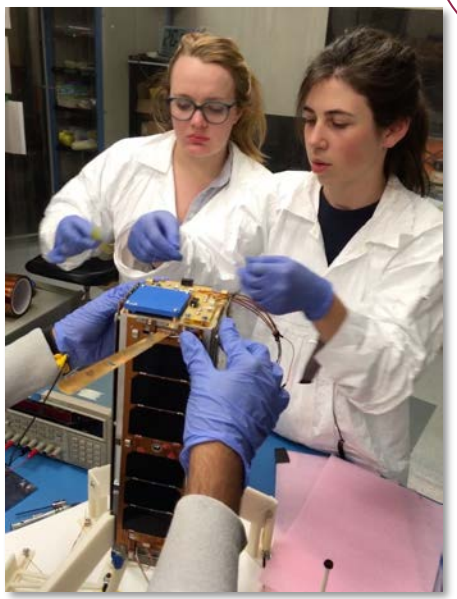
Visiting International Undergraduates and Masters Students Hosted at SERC:

SERC Publications and Presentations



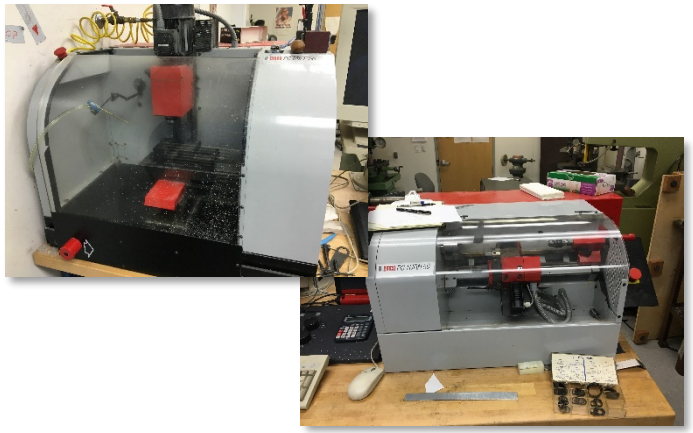
SERC emphasis is “hands-on”… applied research focus




SERC fabrication and integration facilities

Machining Equipment

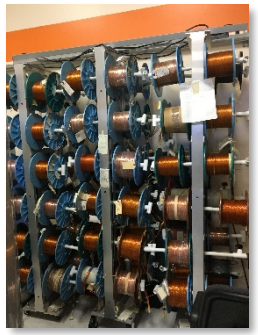


CNC Mill and Lathe

3D printers

Current Lab Space:
- 2 Electronics Labs
- 1 Integration and Test Lab

Current Engineering Spaces:
- Seating for up to 15 students at one time
- Conference Room facilities available



Basic electronic equipment and Flight Wire stores

Optical Table

5k compressor

Class 100k Cleanroom

New for 2020:
- Reflow Oven for PCB Boards
- Laser Cutter for custom boards and parts
- Pick and Place PCB machine (wish list)

Analysis Tools include STK, ESATAN, NX Suite, Solidworks Suite, CADENCE

SERC supports constant inputs to academics …

- ASTE fully ABET Accredited
- Safety & Quality… External Reviewers, Teaching the "ilities"
- Cost efficiency… do more with less

Core Astro Courses

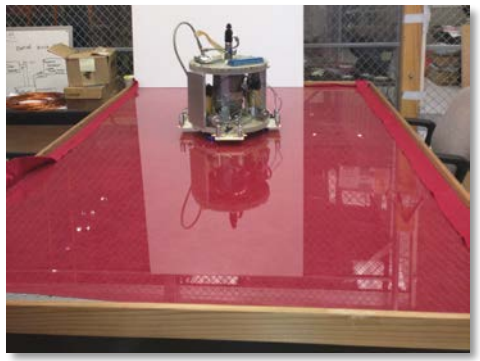
- **ASTE 101L: Introduction to Astronautics** (4.0 units)
- **ASTE 291: Team Projects I** (1.0 units, max 4)
- **ASTE 331a: Spacecraft Systems Engineering** (3.0 units)
- **ASTE 470: Spacecraft Propulsion** (3.0 units)
- **ASTE 490x: Directed Research** (1.0-8.0 units, max 12)
- **ASTE 491: Team Projects II** (1.0 units, max 4)
- **ASTE 505a: Plasma Dynamics** (3.0 units)
- **ASTE 520: Spacecraft System Design** (3.0 units)

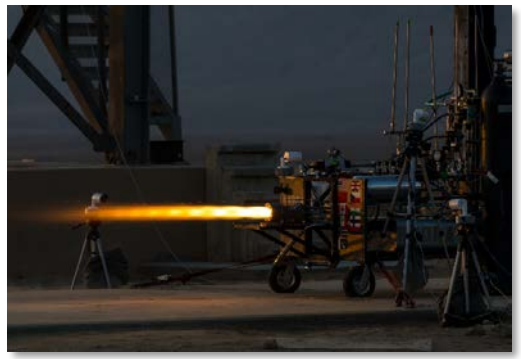
Hands-On Courses

- **ASTE 566 *Ground Comm for Satellite Operations***
- ***ASTE 291/491 RPL, Lunar Lander, Microsatellite Projects***

New Curriculum

- **ASTE 524 *Human Spaceflight***
- ***ASTE 561 Human Factors of Spacecraft Operations***





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Ok…so why is space important?

Today:

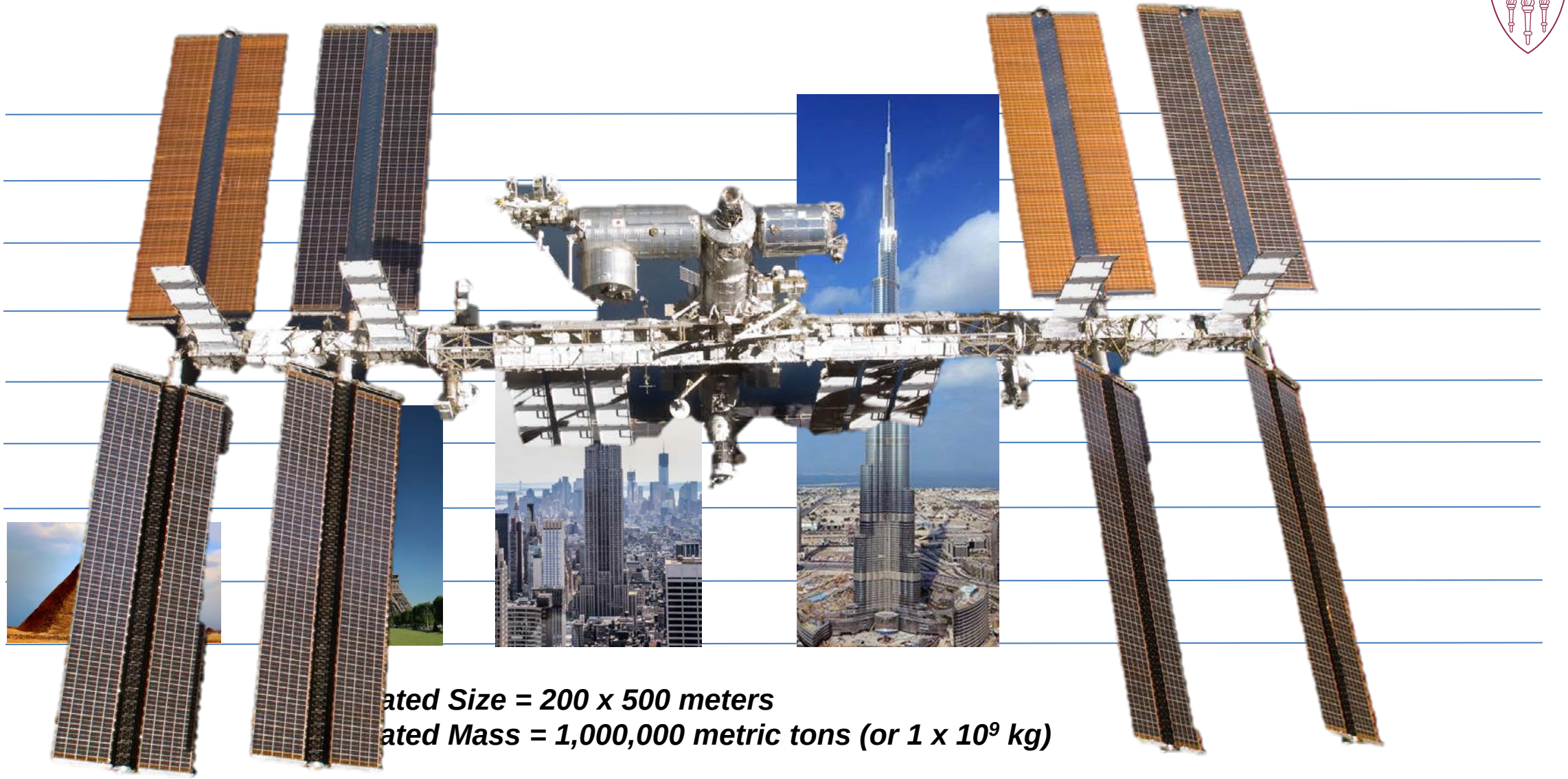
- Radio/TV
- Local/Cell Calls
- GPS
- Weather
- Internet connectivity
- Banking
- Agriculture
- Research

Future is about going beyond Earth:

- Power Beaming
- Fuel Depots
- Interplanetary Transport
- Planetary habitation (Moon/Mars)

SERC's Goal: Enable Building Next Generation in Space

Some perspective…



ated Size = 200 x 500 meters
ated Mass = 1,000,000 metric tons (or 1 x 10^9 kg)

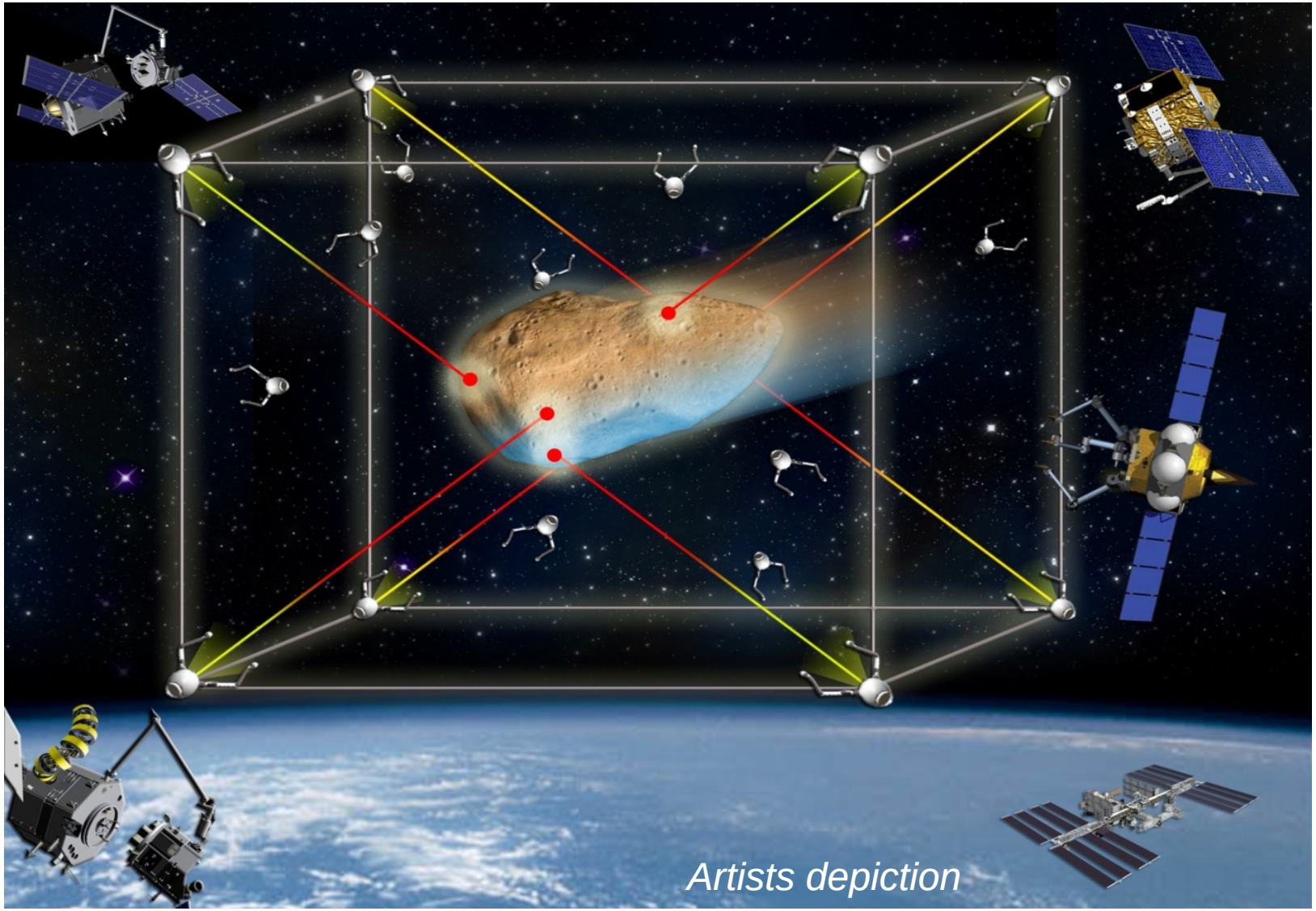
To build big… simple theme's enable Big breakthru's

Talk to everyone! – ***Miniature High Performance Apertures & GS***

Grow naturally! – ***Biologically inspired cellular aggregation***

Connect and disconnect to anything – ***CLING Genderless RPO and Docking System***

See everywhere – ***Multi-visual data fusion***



Make rendezvous easy – ***RPO Standards and Flight Techniques***

Make Swarms cooperate – ***Genetic Algorithms for safe formation flight***

Reach out and grab anything – ***Octopus robotic gripper***

Interact with a new body – ***LEAPFROG***

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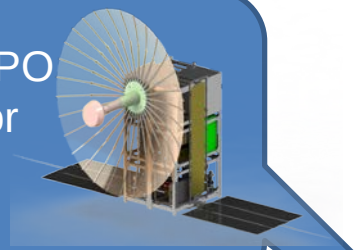
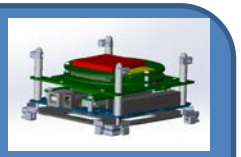
THEME to develop and build advanced communication: Create a Nano-Sat flight capability at USC!

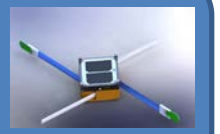
Small RPO Inspector Design



Maestro Multi-Core Processor Flight Experiment

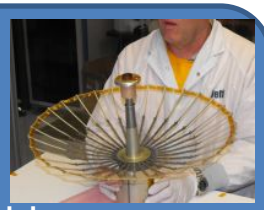


COTS Sensors measure magnetosphere at 1/1000th cost



0.5 m RF Dish Deployable

Used by JPL, spun off to commercial use

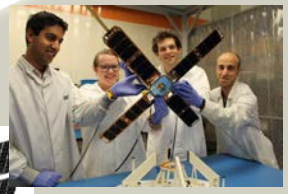


MAGNETO

2020

1st All USC Student Built Satellite – Launch Planned Summer 2020

DODONA



2019

Built & Delivered, No Launch yet

eXCITe

2018

Launched Successfully – Host S/C did not operate

Aeneas

2012

Launched Successfully – Still in Orbit!

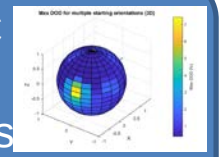
Careus

2010

Launched Successfully – Deorbited

Quad Monopole Deployer & Comm

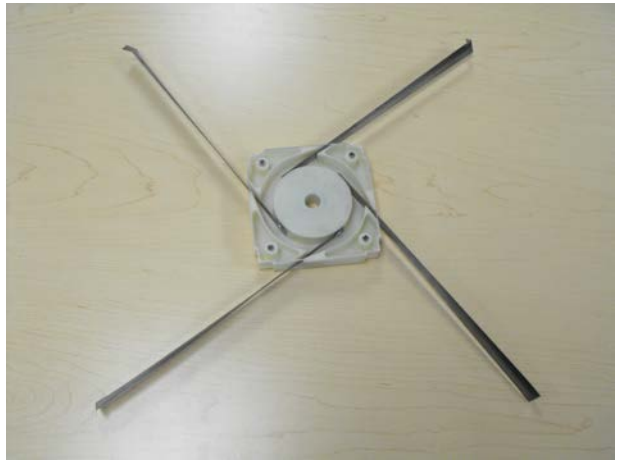
Adv. GNC Control Algorithms

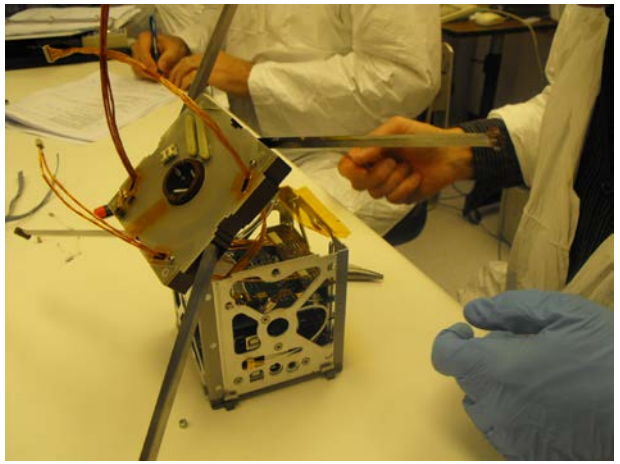


SERC demos, Some "World firsts" in Nano-satellite class platforms

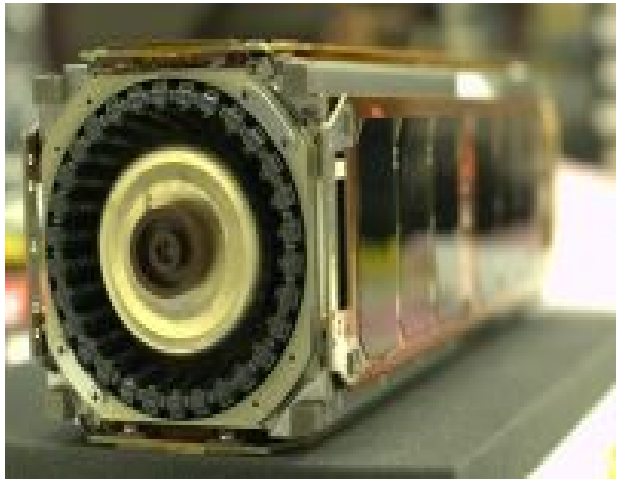
- Multi-functional structure propulsion system w/NGST
- Largest (~.5m) antenna deployable
- High performance embedded computing (HPEC)

Advanced Apertures for nano-sats

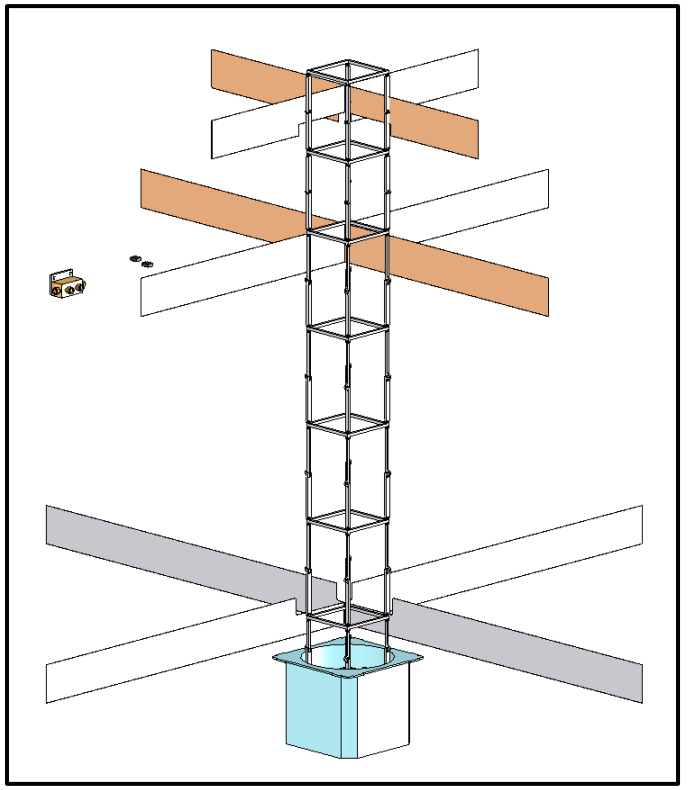




UHF Quad Monopole-Two Frequencies, Built and Flown



S-Band High Gain Antenna, built and flown



High Gain Yagii, Designed

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Talking to Space…USC's Satellite Ground Station

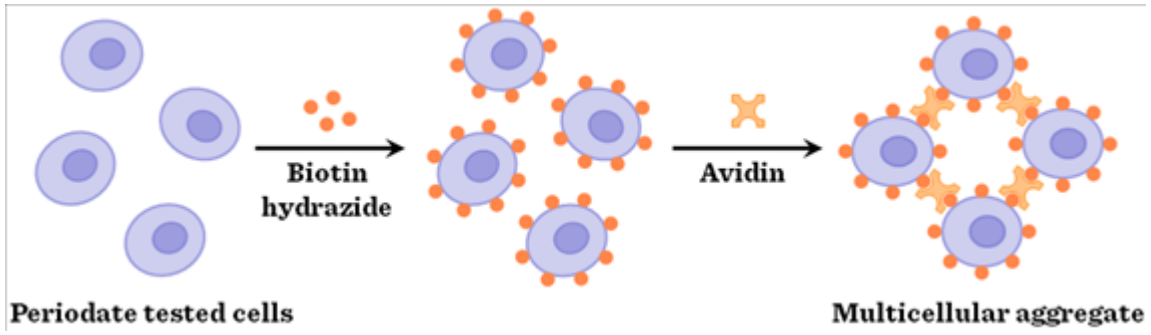
4.5m Dish (L-C band)

5m Yagii (UHF/VHF)

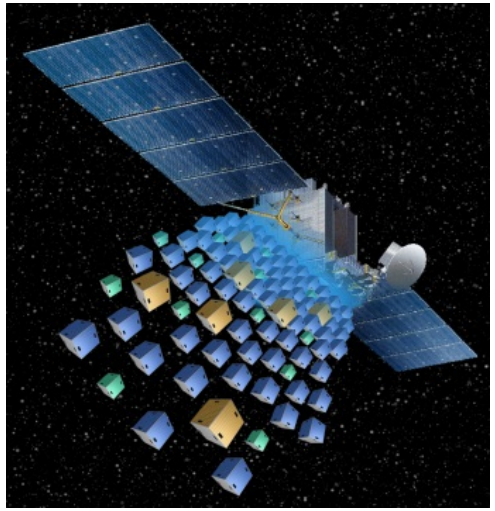
Ground Control Station for simealtaneous Ops

THEME to Grow Platforms in Space: Change monolithic to cellular space platforms that aggregate!

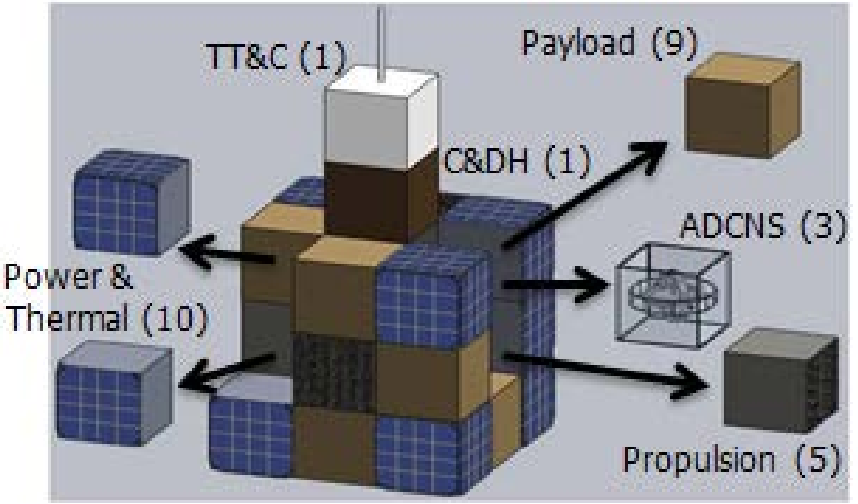
Biological System



Space System

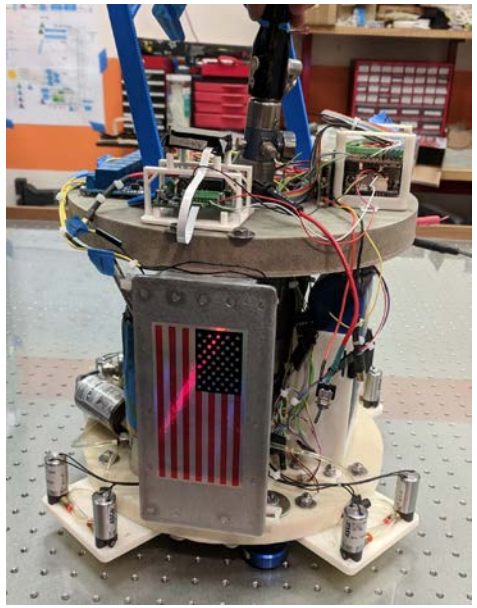


Artists' concept

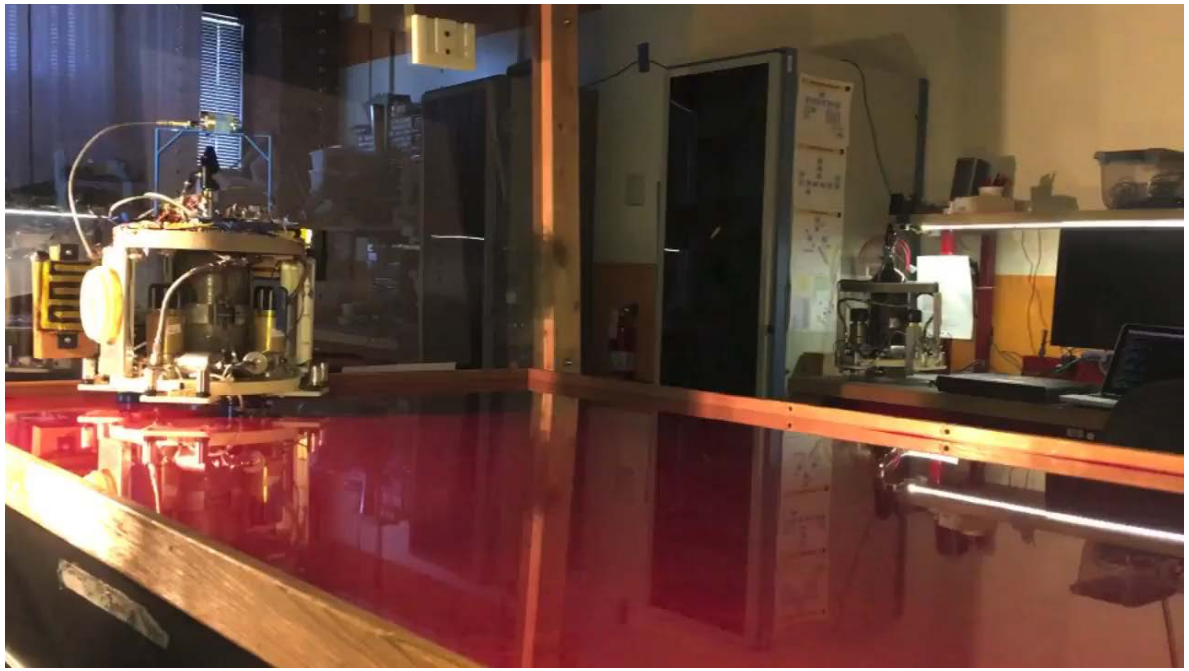


SERC Testbed developed simple “float bots” to simulate satellite movement on frictionless table

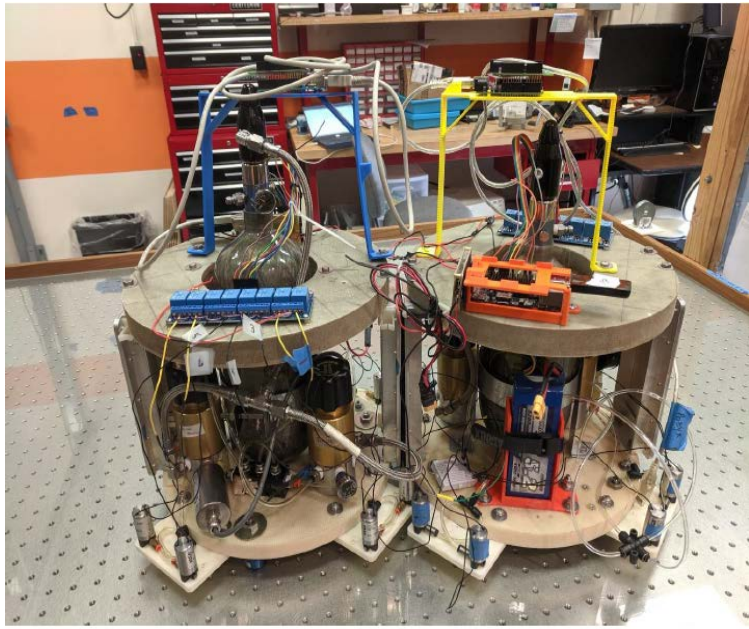
“Pseudo-Satellites” used as test platforms



Test platforms “Float” on air bearing surface, provides space-like environment



By connecting two or more “pseudo-Sats” can demonstrate aggregation behavior



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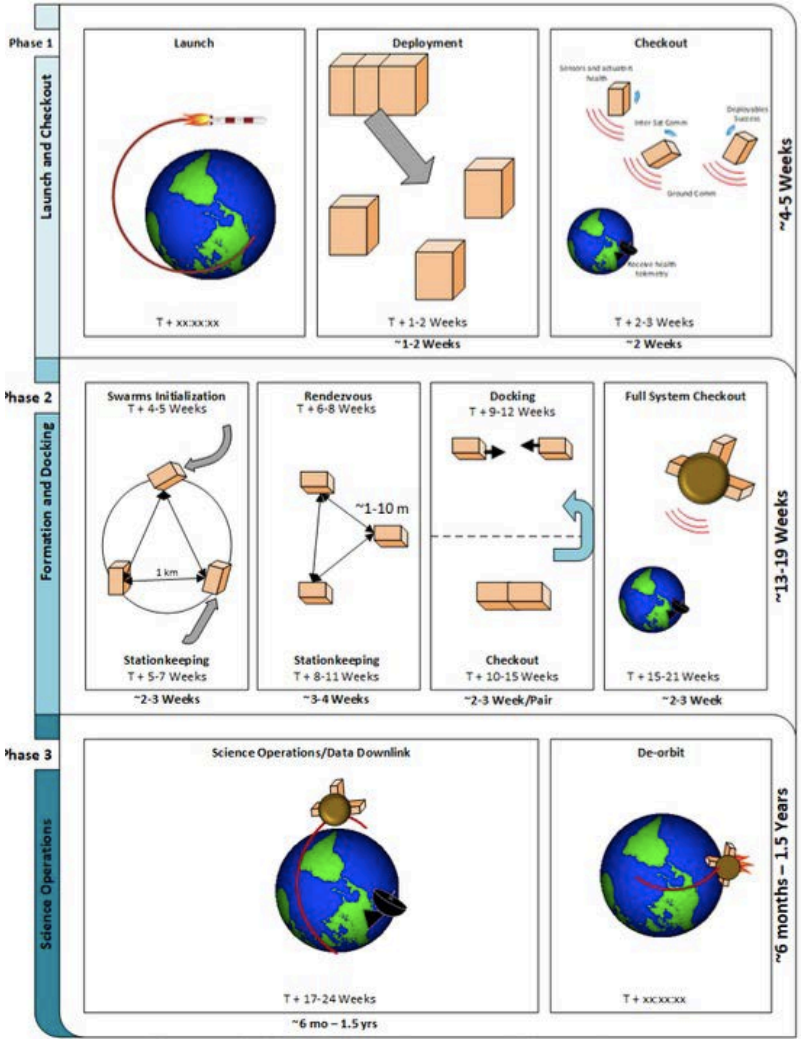
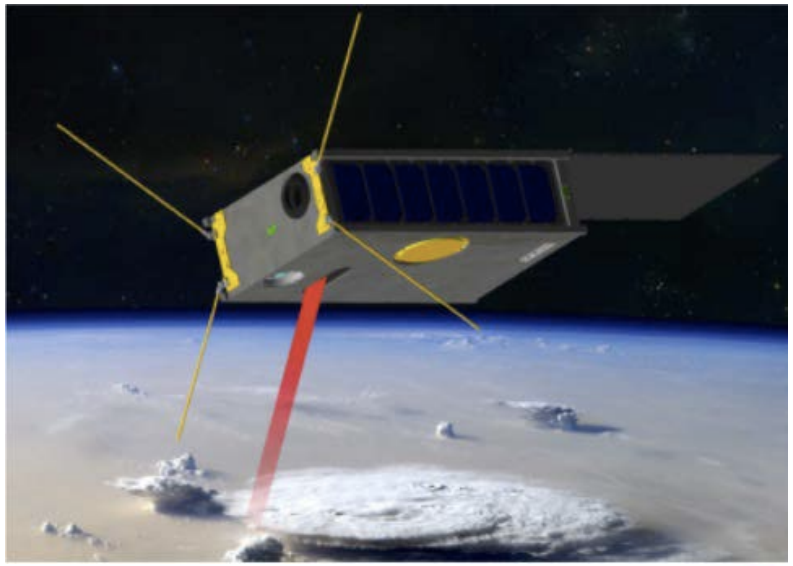
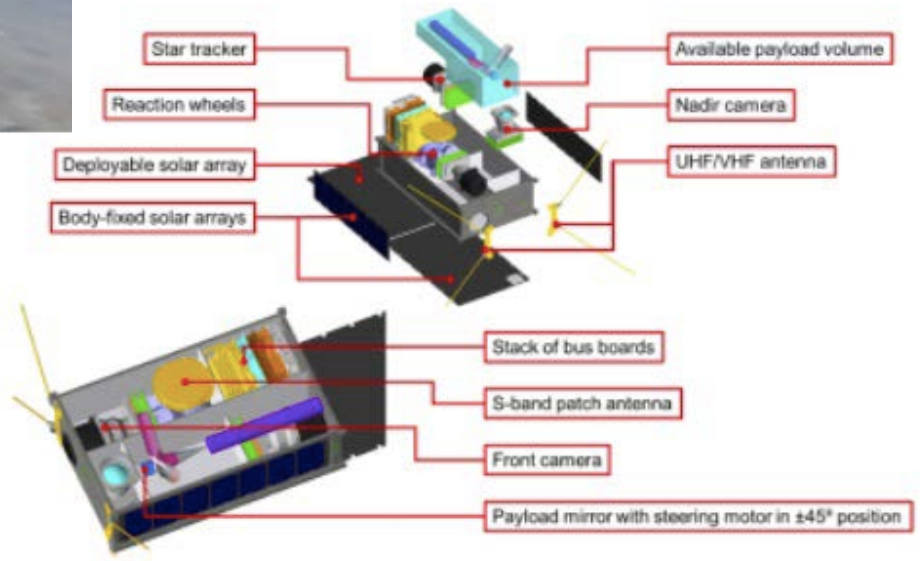
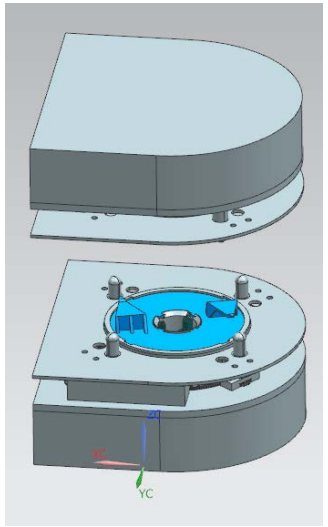
"Space Swarm" project with JPL designing mission for on orbit Cubesat Aggregation

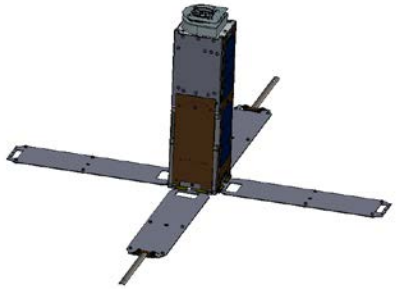




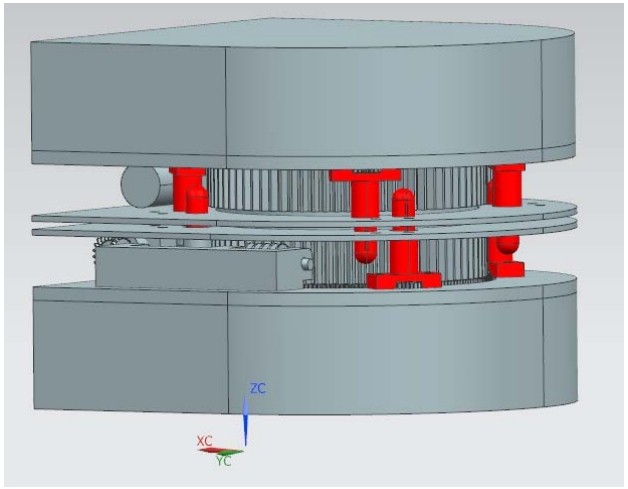


THEME to connect anything: "CLING", An Advanced Genderless Docking System

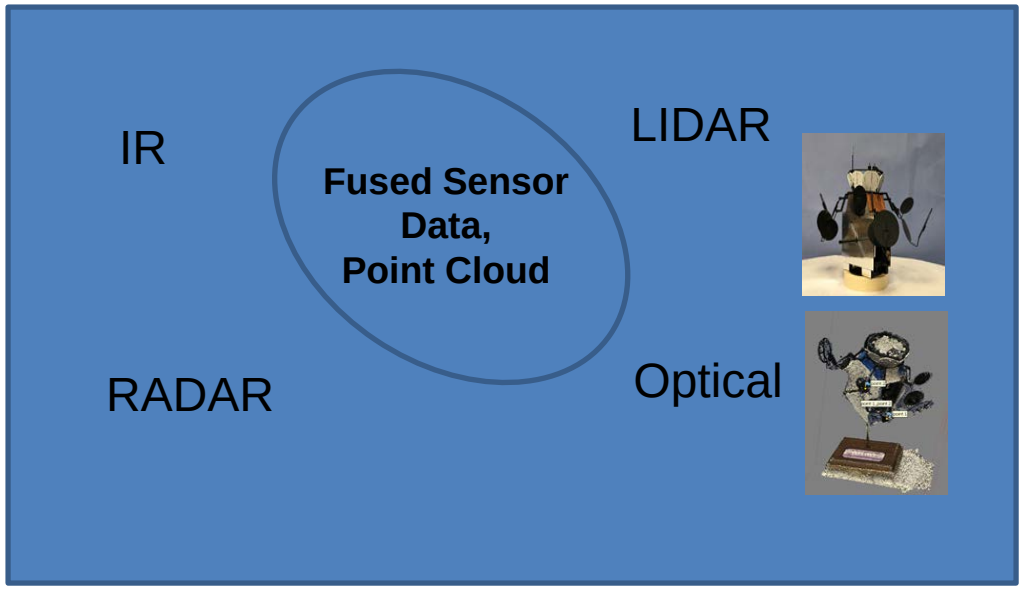




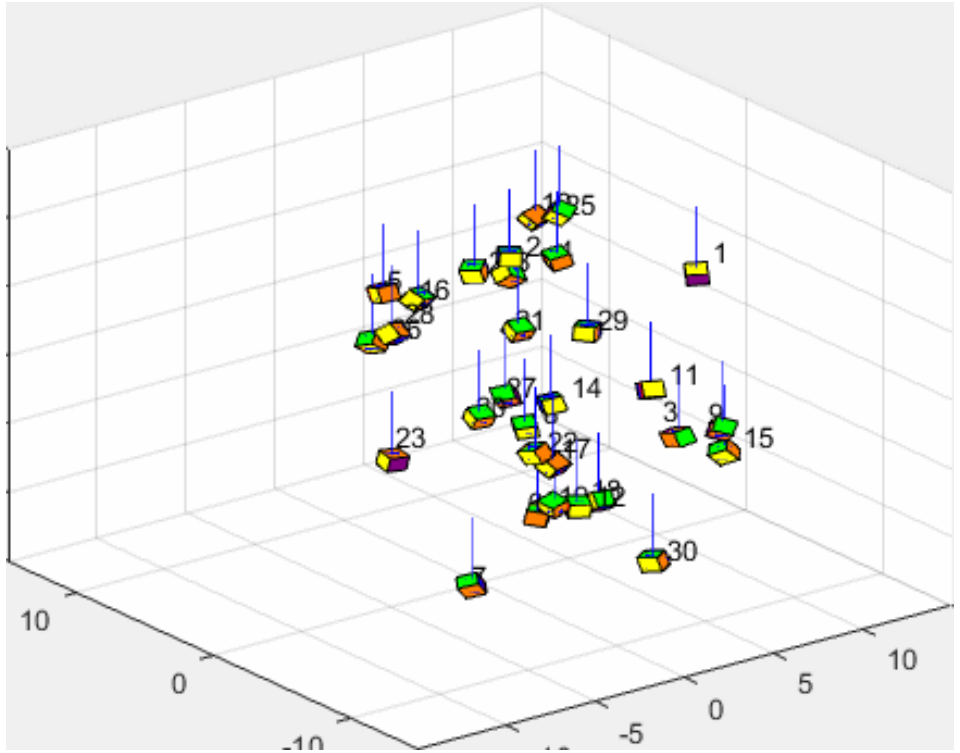
Invented by Dr Berokh Khoshnevis



THEME to see all around you: Multi-sensor image fusion



Multi-Modal Sensor Fusion and Point Cloud Creation

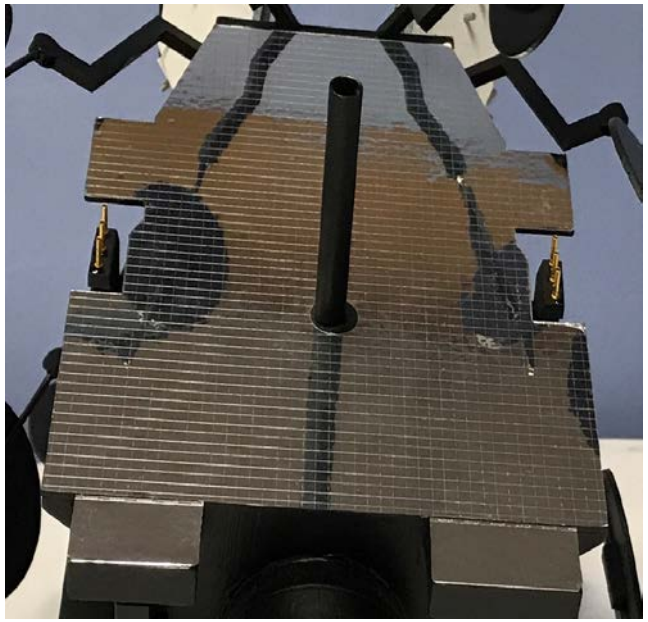


Cooperative Localization of a Compact Spacecraft Group using Computer Vision

PhD research for William Bezouska, now Dr Bezouska!

Challenges to resolve…

Photogrammetry Problems

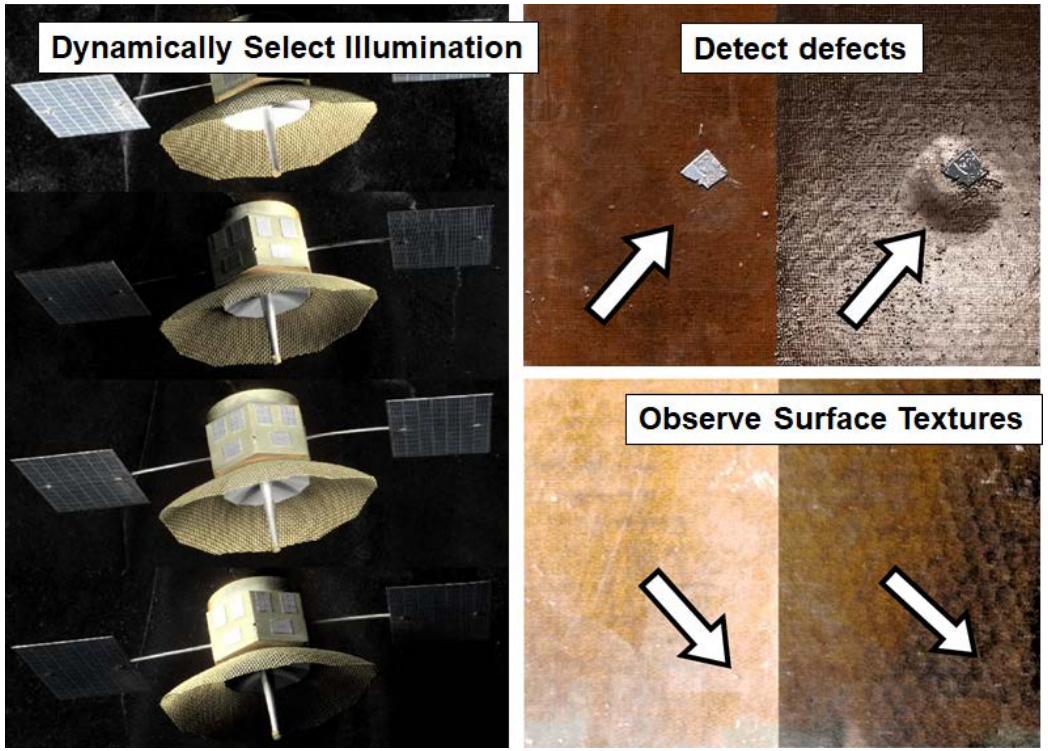


Reflective Surfaces

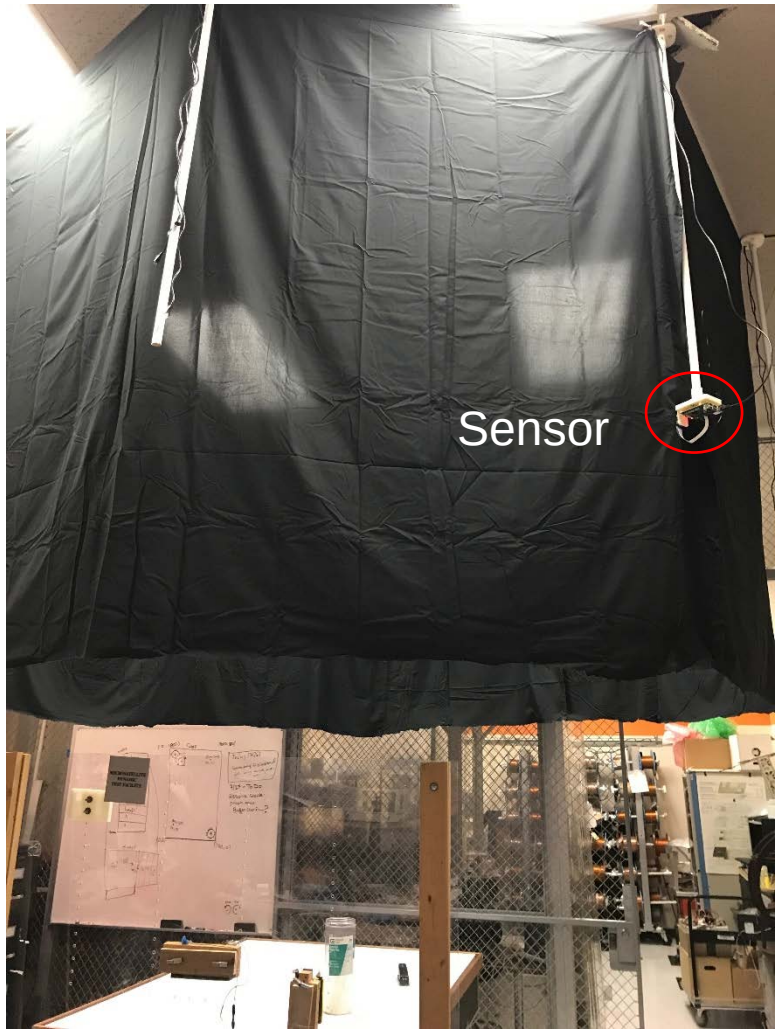
Background
Recognition

Thin
Objects

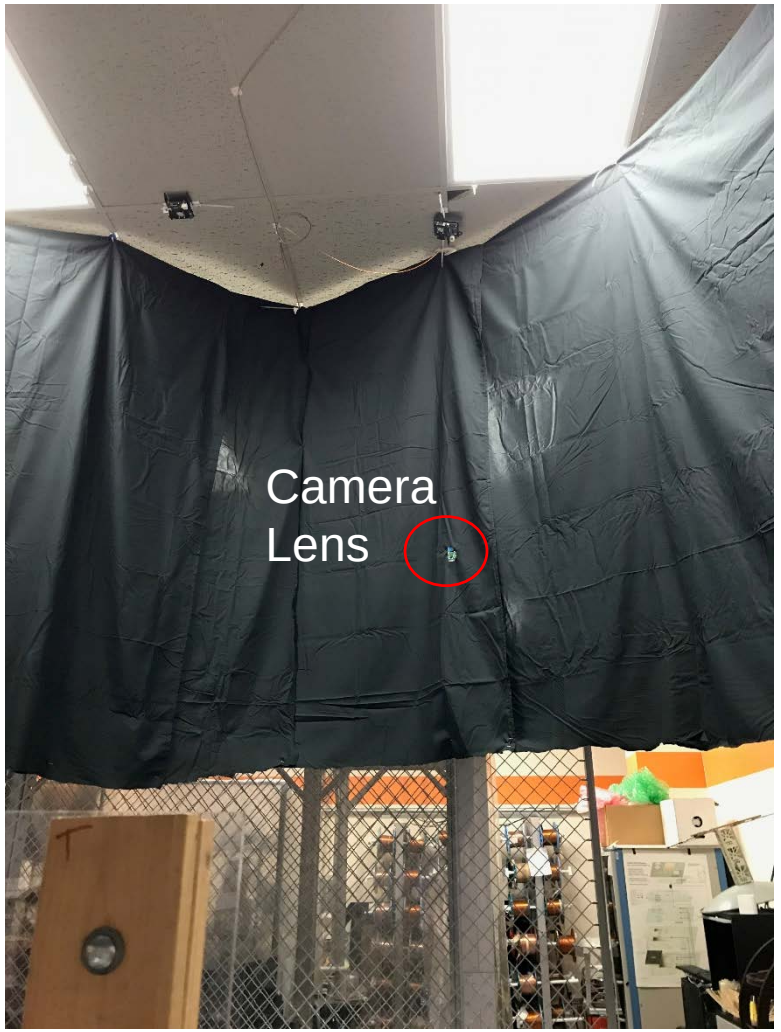
Lighting/contrast challenges



Visualization of Test Setup



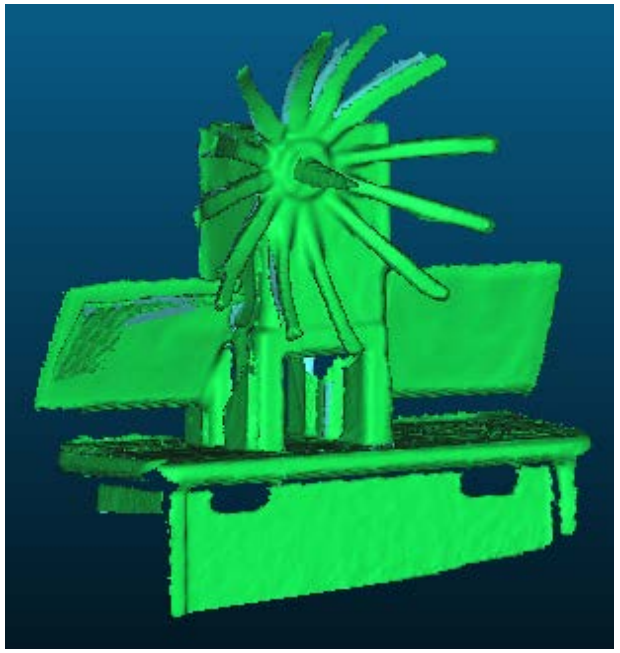
Outside View

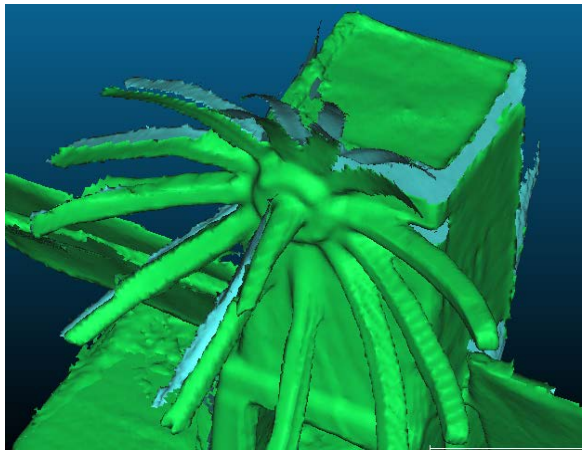


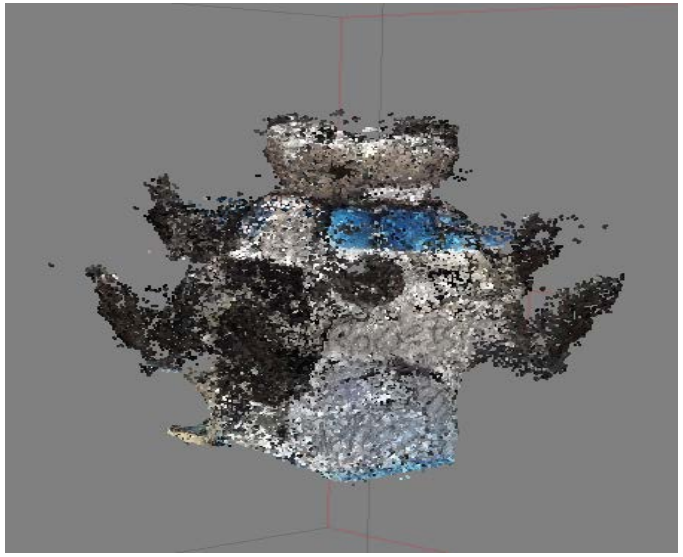
Inside View

Simulating the sun

Some Early Trails with Radar/Lidar and Sofware

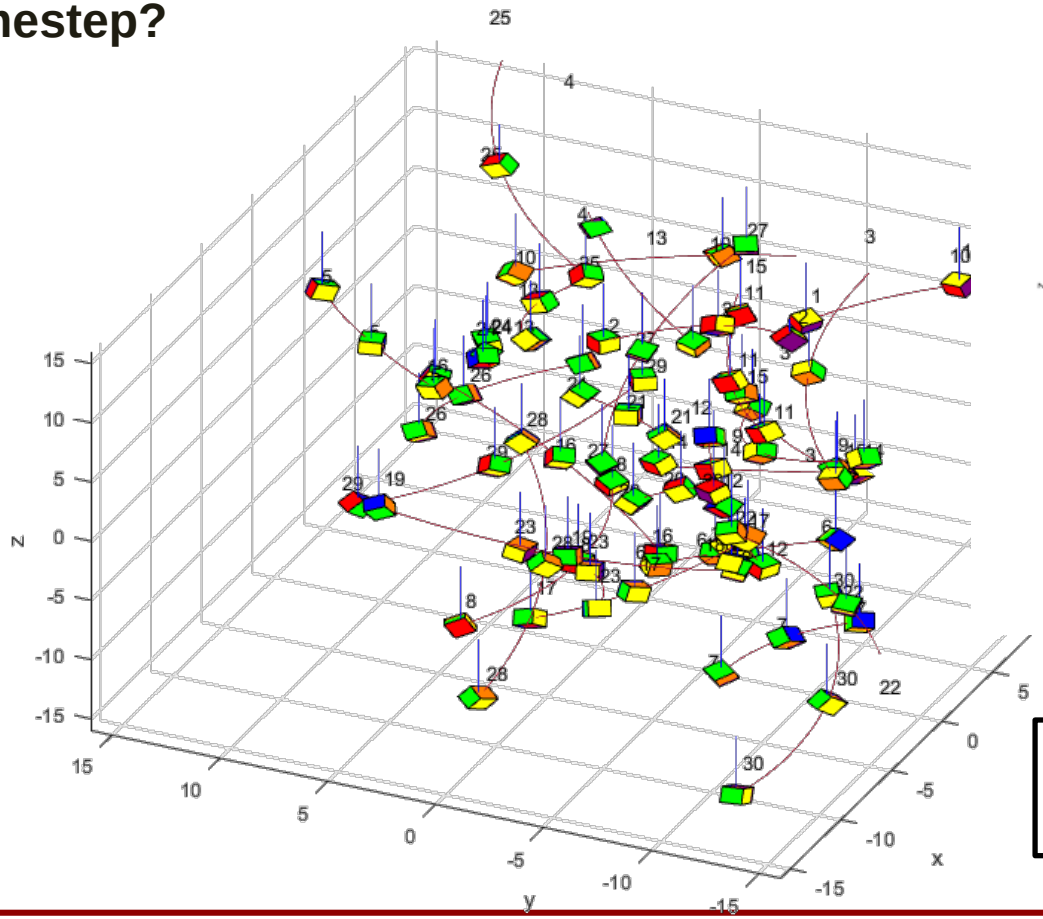






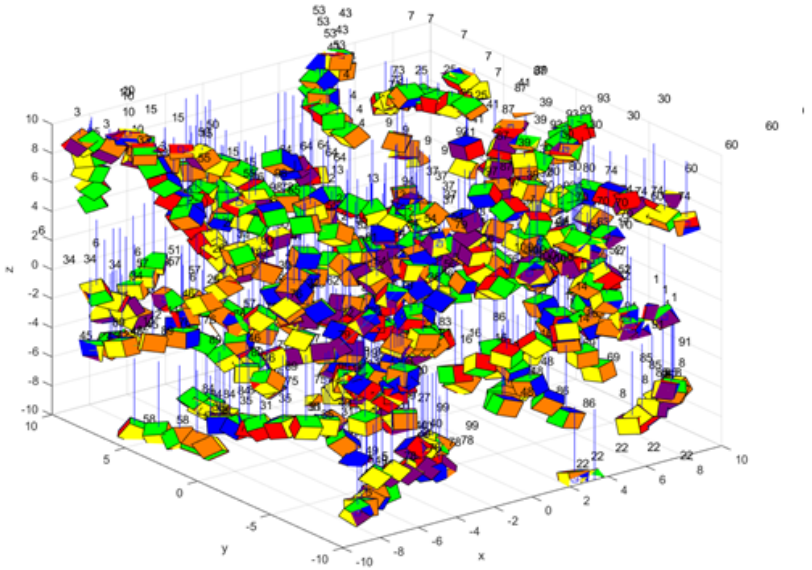
Dr Bezouskas premise: Instead of multiple sensors on one satellite, how about multiple satellites each w/cameras?

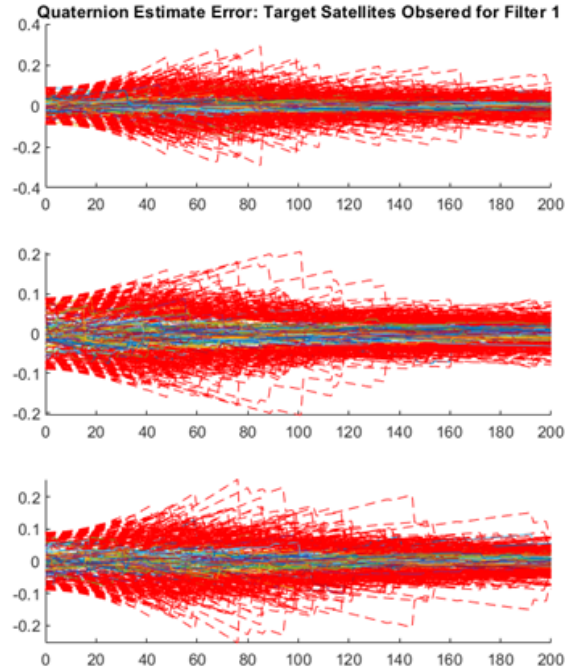
Research Question: What is the best subset of sensors to use at each timestep?



Sensor Selection Enables Large Groups

Example: 100-satellite swarm
Infeasible with complete graph





30 satellites = measurement vector with 6,097 elements!

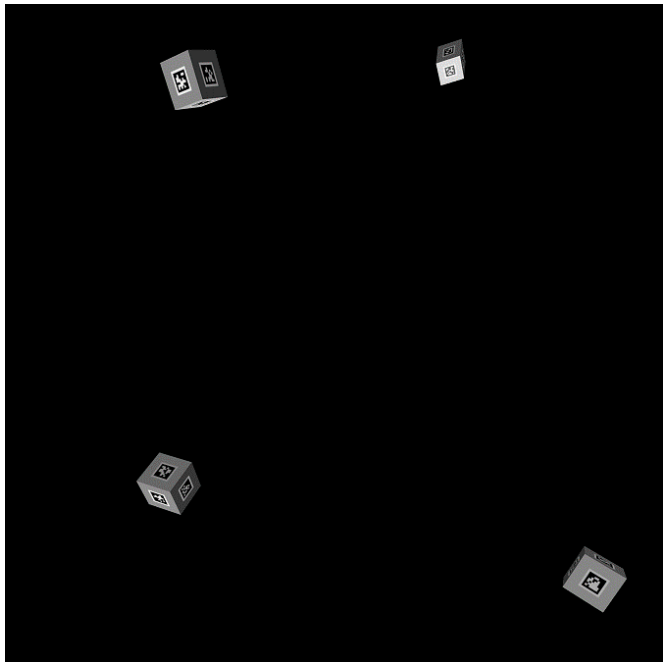
Simulation environment is first step…

Simulation Environment Overview – Wide Angle

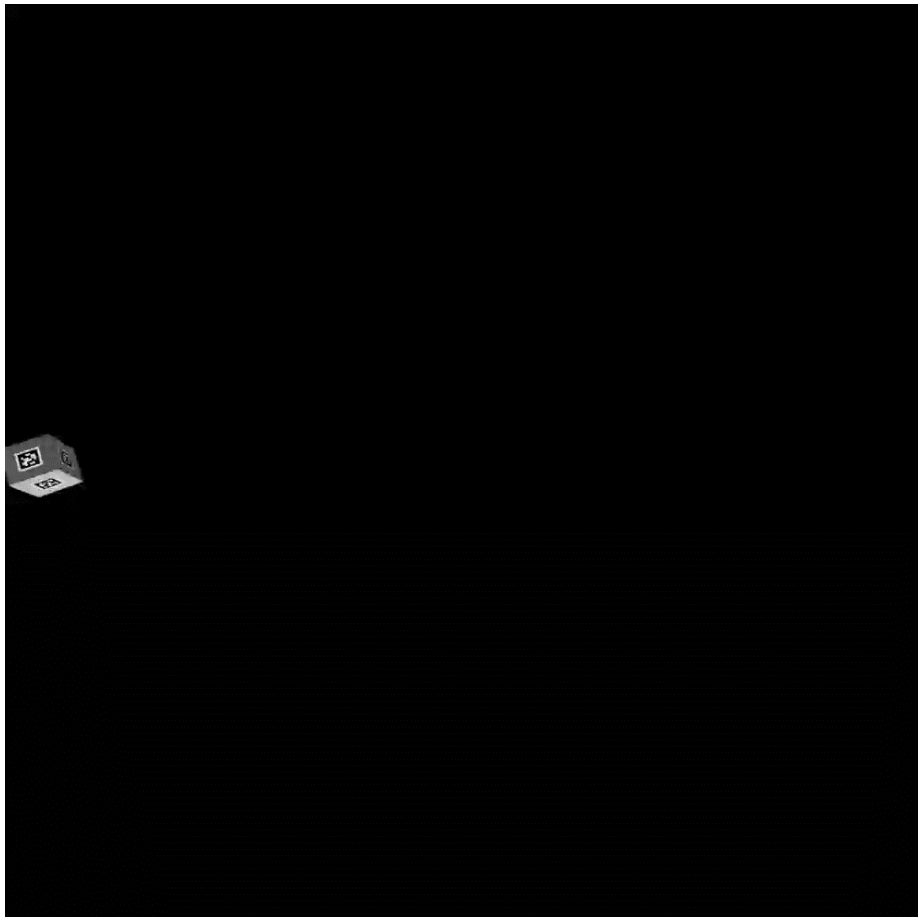
Python-based automation
- Dynamical simulation in MATLAB
- Rendering in Blender

Cameras
- 16 mm focal length
- 32 mm senor size
- 90 degree field of view
- 2000 x 2000 pixel images

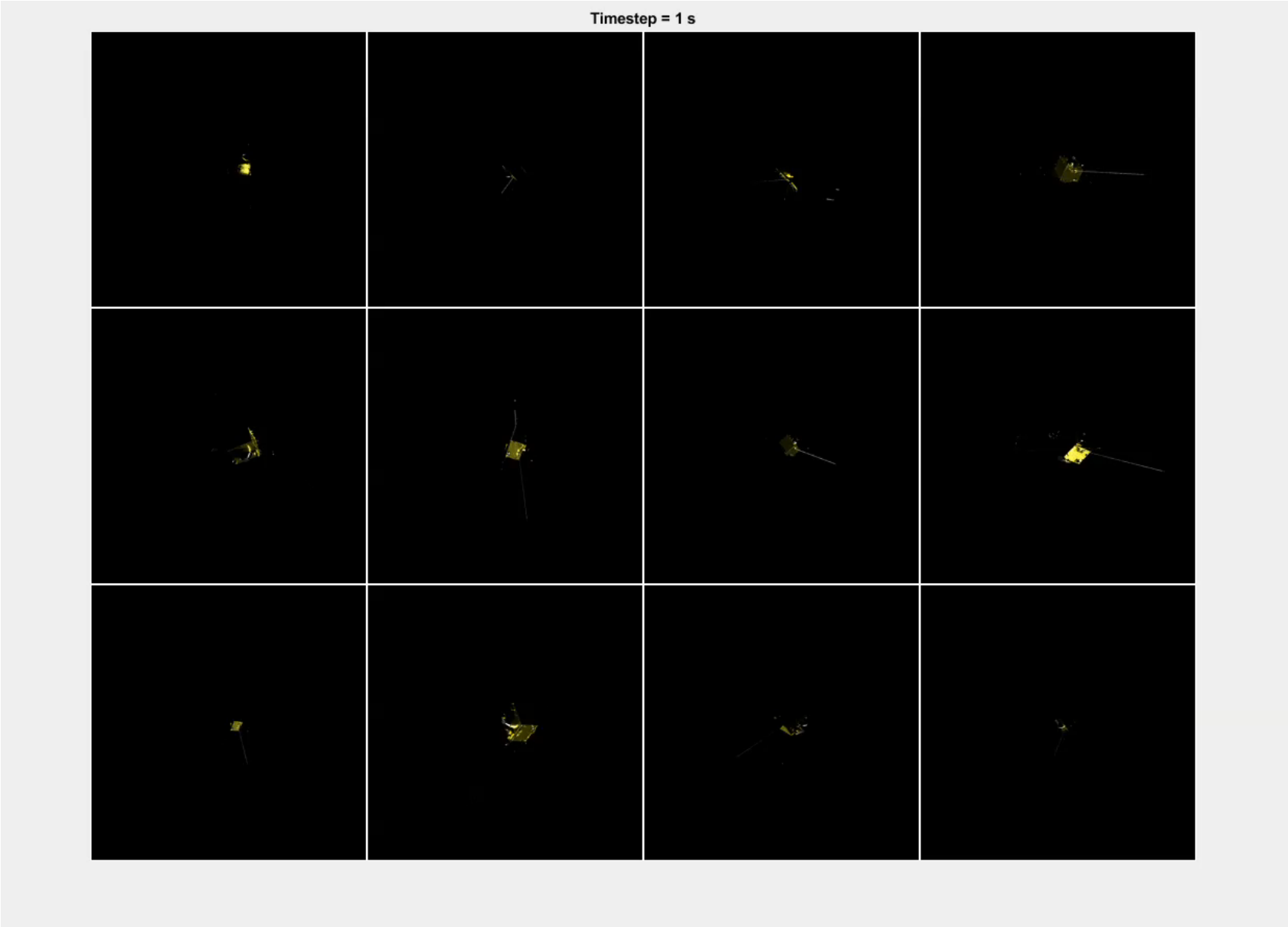
Fiducials (AprilTags)
- Each face has unique tag ID
- Included as texture map in Blender



Sample image frame observing four satellites

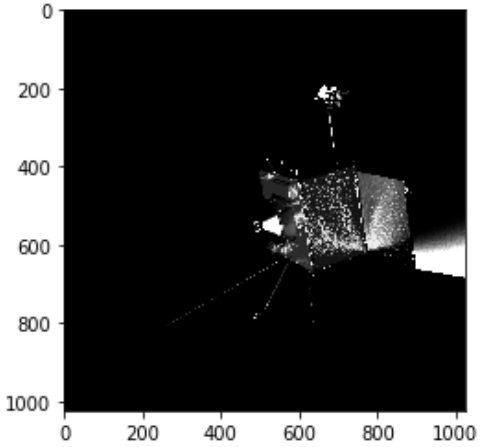


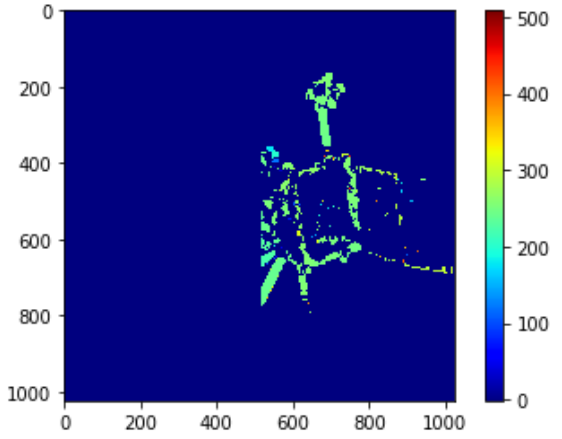
Lighting is a big deal…



What it all means? Multiple cameras on multiple spacecraft can provide a unique Pose Estimation Pipeline to navigate around each other!

1. Grayscale





2. Disparity Map

3. Point Cloud

4. Registration

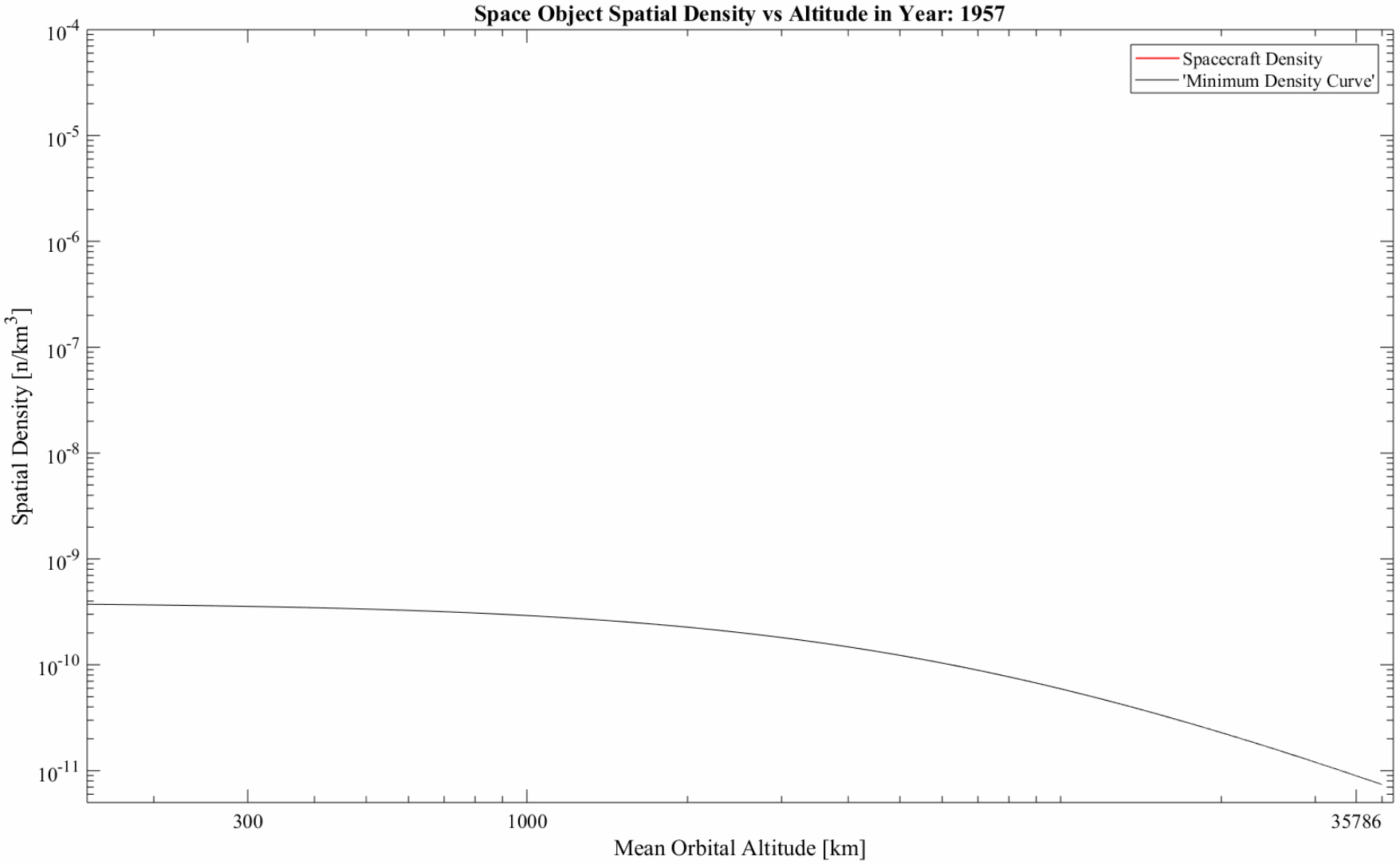
THEME to make rendezvous safe… USC SERC part of new International Commercial Consortium

CONSORTIUM FOR EXECUTION OF RENDEZVOUS AND SERVICING OPERATIONS (CONFERS)

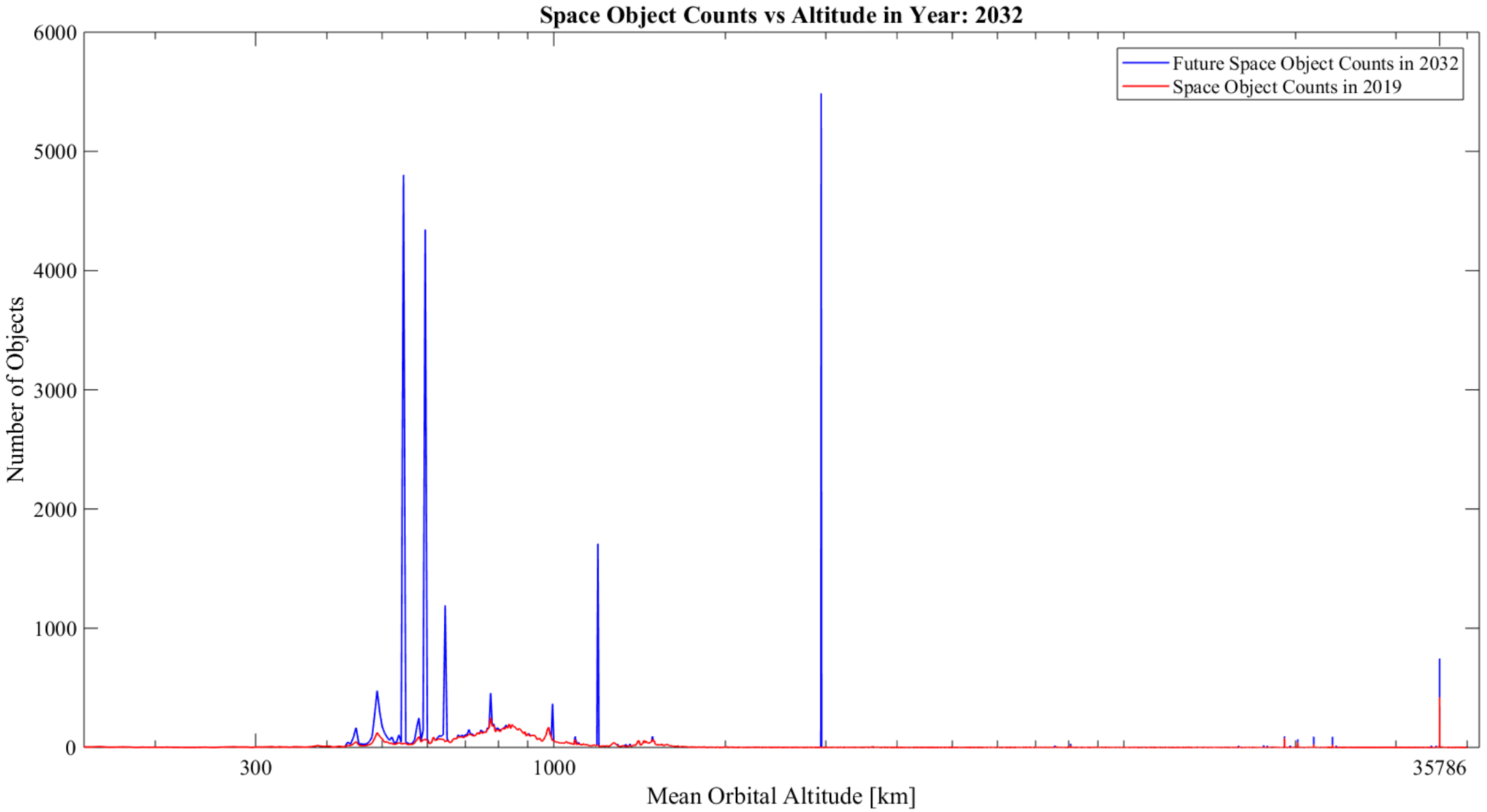
Goal: Develop and introduce industry-consensus standards for new emerging applications for cooperative rendezvous and proximity operations and on-orbit servicing (RPO & OOS)

USC Space Engineering Research Center

Why does it matter? there are a lot of objects around Earth!



Historical/Projected Spacecraft numbers will only go up…

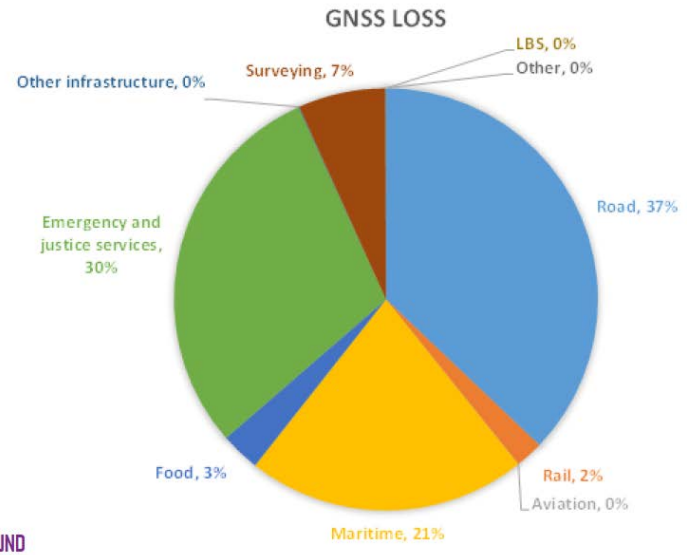


Quick example of Economic Impact analysis on loss of space assets that affect people/every day life…

- **Economic loss of GNSS for 5 days from any cause…**

Impact of Loss of GNSS (for 5 days)

- The economic impact to the UK of a five day disruption to GNSS has been estimated at £5.2bn.



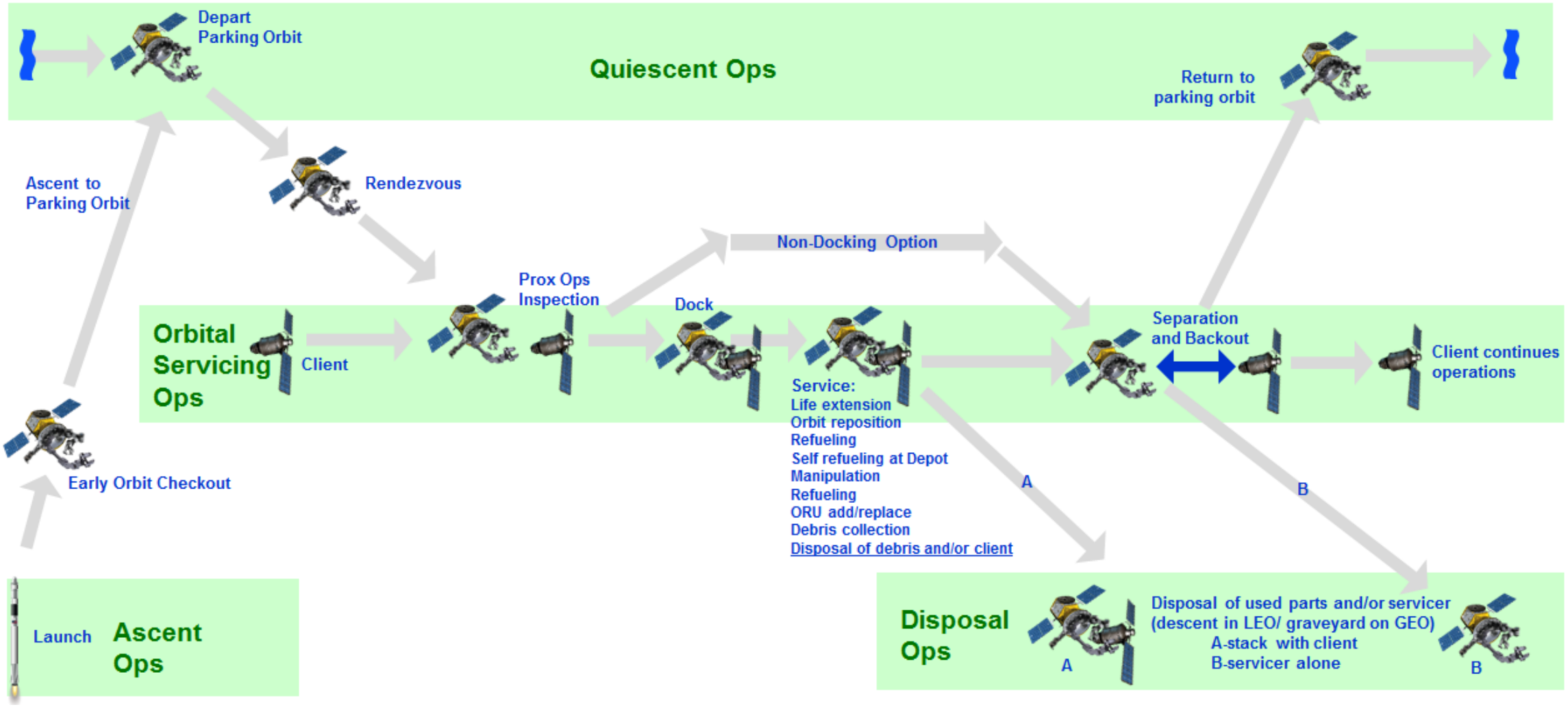
Consider this a LOWER BOUND

"Economic Impact of the loss of GNSS to the UK", Andy Proctor, UK Government PNT Group, Delegate to ESA Board of Navigation, Nov 2017

Critical Applications

Infrastructure	Aspect	RAG	Loss of GVA (direct+secondary) (five days)	Loss of utility benefits (five days)
Space	Satellite communications		£22.5m	*See Maritime transport infrastructure*
Transport infrastructure	Maritime transport infrastructure		£1,069.3m	*See Maritime usage applications*
Application	**Aspect**	**RAG**	**Loss of GVA (direct+secondary) (five days)**	**Loss of utility benefits (five days)**
Surveying	All applications		£344.8m	£-
Rail	Automatic train doors			£2.8m
	Train cancellations		£77.7m	£12.7m
Road	Navigation		£-	£1,869.7m

What is "Space Servicing"? Reaching out an touching objects to do something…in space!



To enable safe operations CONFERS is pushing standardizing RPO and OOS operations…

"Rendezvous and Proximity Operations (RPO)": Timelines, actions, maneuvers between two different space platforms from distance (>100km) to within several meters

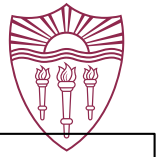
First year tech focus: Complete

"On-Orbit Servicing (OOS)": Timelines, actions, maneuvers, interactions, manipulations, between two different space platforms within several meters to contact/dock/grapple/connect etc.

Second year tech focus*: In Progress*

1. **Database survey of past RPO missions revealed no specific "standard" on rendezvous schema (distance, velocity, gates, phases, etc)**
   1. No concurrence on use of specific nomenclature or lexicon to describe rendezvous
   2. No concurrence on graphical representation or depiction of "rendezvous"
2. **First set of RPO safety metrics created to begin discussions with industry**
3. **Initial survey with first industry members candidates**
4. **RPO survey results and metrics presented in Bremen Germany at IAC**

Results of 1st year: Three initial RPO Metrics created for discussion



#1: Contact Velocity

#2: Remote Influence

#3: Control Accuracy

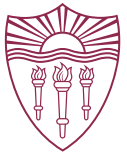
Metric value $x = \frac{v_{projected}}{v_{max}}$ **Metric value** $x = \frac{\omega_{projected}}{\omega_{max}}$ **Metric value** $x = \frac{MCO}{ECD}$

- **Inputs:** Physical values of Servicer and Client Spacecraft, desired performance
- **Outputs:** Unitless ratios; less than 1=safe, greater than 1=risky

Metrics applied to past (and current) missions appear to follow ratio of "low riskiness"…

Mission Details				Metrics		
Name	Primary Organization	Target	Date	Contact Velocity	Remote Influence	Control Accuracy
STS-41C	NASA	Solar Max	4/9/84	0.1523	0.154	0.245
Dragon	SpaceX	ISS	5/22/12	0.0295	0.00585	0.0198
Apollo 11 (LEM)	NASA	CSM	7/21/69	0.8119	0	6.45
MEV-1	Northrop Grumman	Intelsat-901	2020	0.3221		
RESTORE-L	SSL	Landsat-7	2022	0.2909		
O.CUBED	Airbus	TBD (GEO)	2023	0.393		

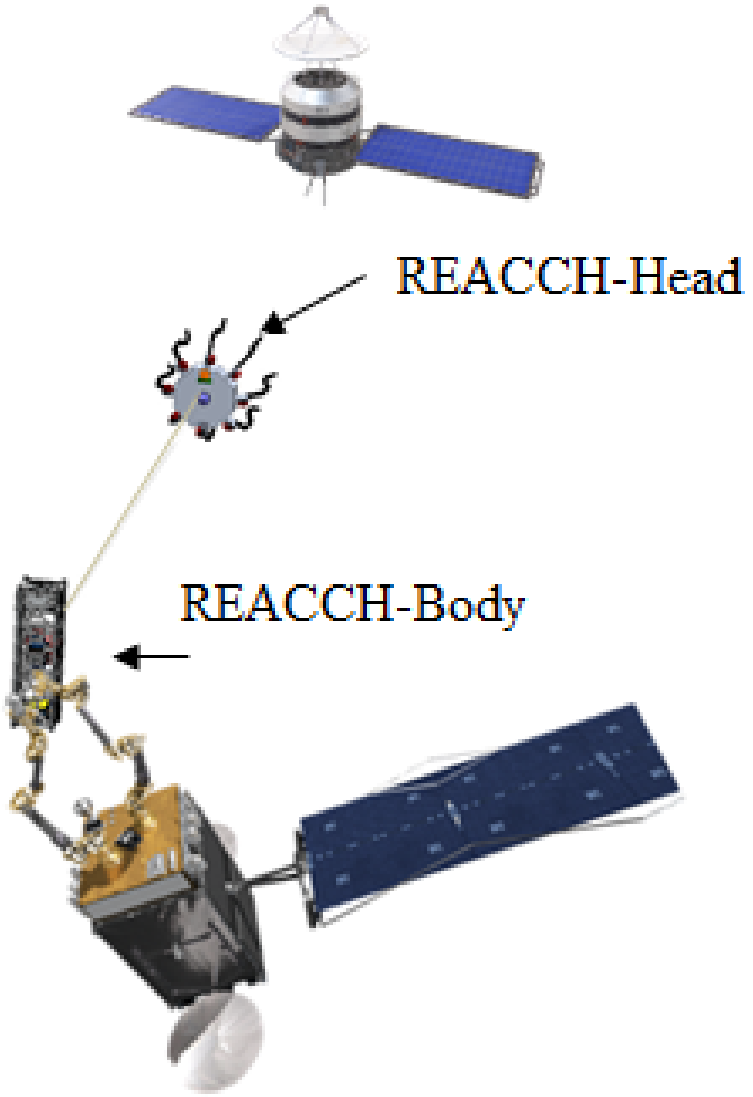
THEME to fly multiple objects safely: Use Genetics!



To be subject of another Seminar, this is just a tease…

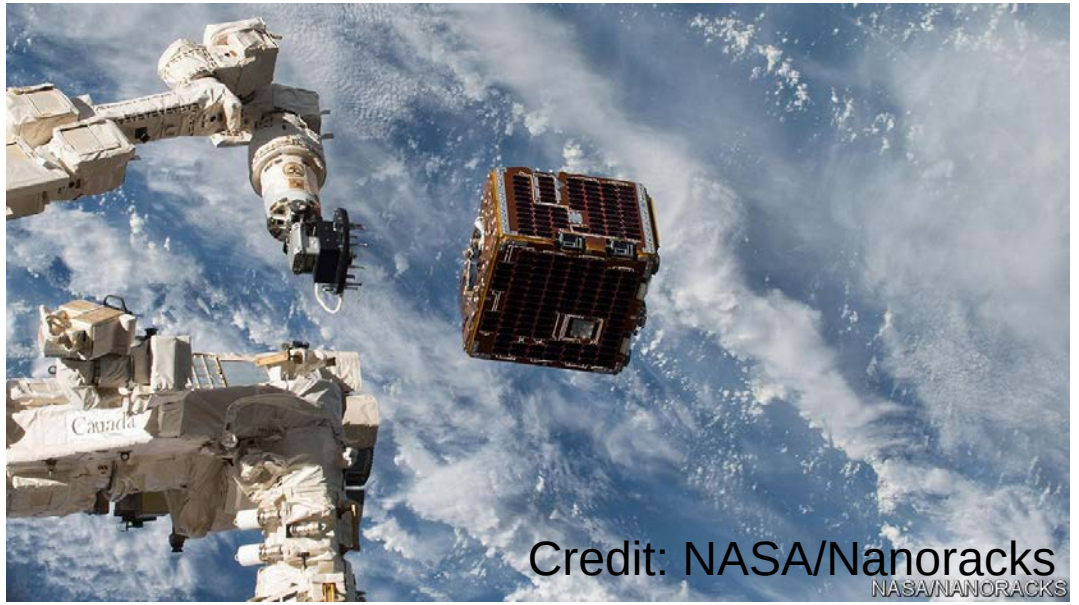
THEME to reach out and grab things safely: Use an Octopus!

- **REACCH**
  - **Reactive Electro Adhesive Capture ClotH**



The problem: current contact docking methods are high cost/risk

- Current methods used…
  - Controlled contact
    - Pre-defined contact area
    - Mechanism integrated before launch
  - Uncontrolled contact
    - Throw nets, magnetics, harpoons



What would we like? A method that is

- Simple
- Easily deployable
- Adaptable
- Low mass
- Low cost
- Safe to use

The Solution? Look to Biology for inspiration…

What combines flexibility, the ability to turn on and off grip, the ability to merge "compliance" with "control" seamlessly?

An 8-limbed mollusc- the Octopus!

Features:

- 8 tentacles
- Compact
- Flexible movement
- Control over individual tentacles
- Can perform gripping/opening
- "Suckers" provide sense and contact

Combines best of compliance & control

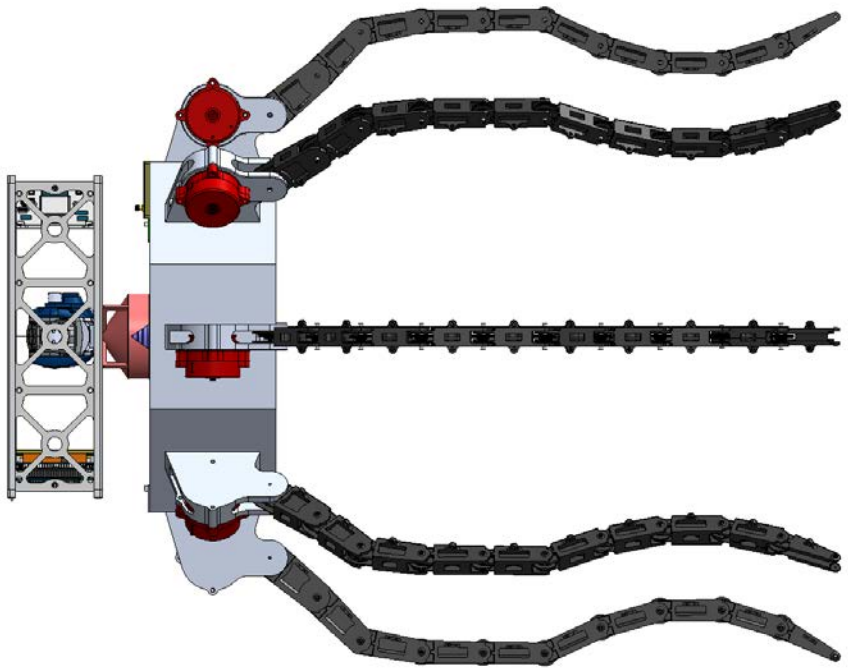
REACCH assembly created as end affector

Base

- Remains fixed to robotic arm
- Contains primary tether/reel mechanism
- Facilitates storage of body pre/post grapple

End Effector Conceptual Design

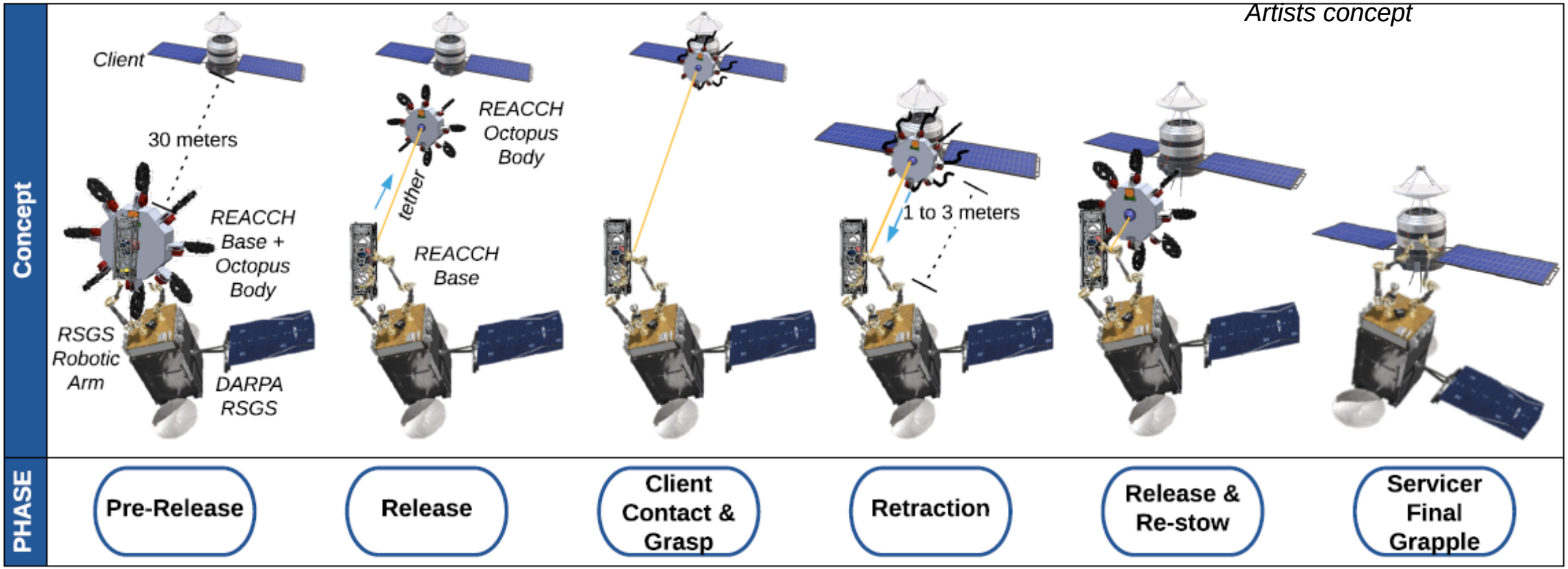
Base (left) – Body (right)



Body

- Contains all required electronics (HVMs, power & comms, control system)
- Pairs of tentacles
- EA/G tiles
- Contact & Stretch Sensing

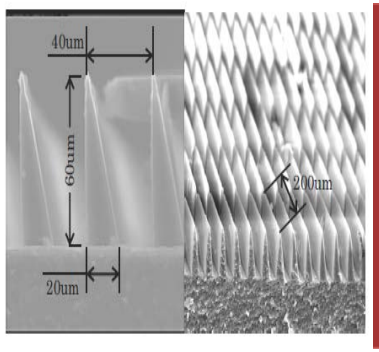
REACCH Concept of Operations

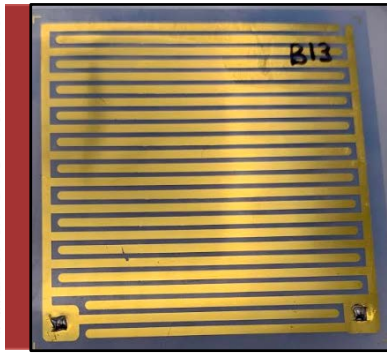


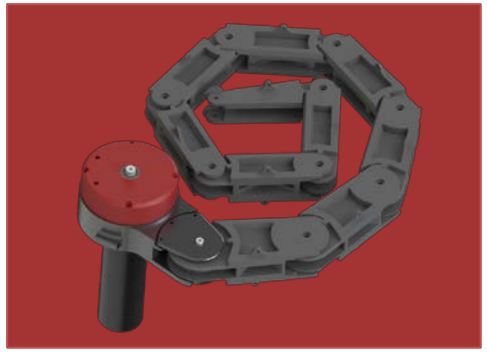
REACCH employed by a servicer platform (e.g. DARPA's RSGS)

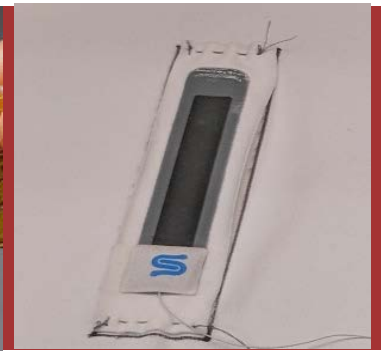
Core Technologies that enable REACCH

- Adhesives:
  - Gecko
  - Electro-static
- Control Element: Tentacles/Backing Spines
  - Segmented or Jointed
  - Continuous
- Compliance Element:
  - Elastic substrates
  - Stretchable sensors



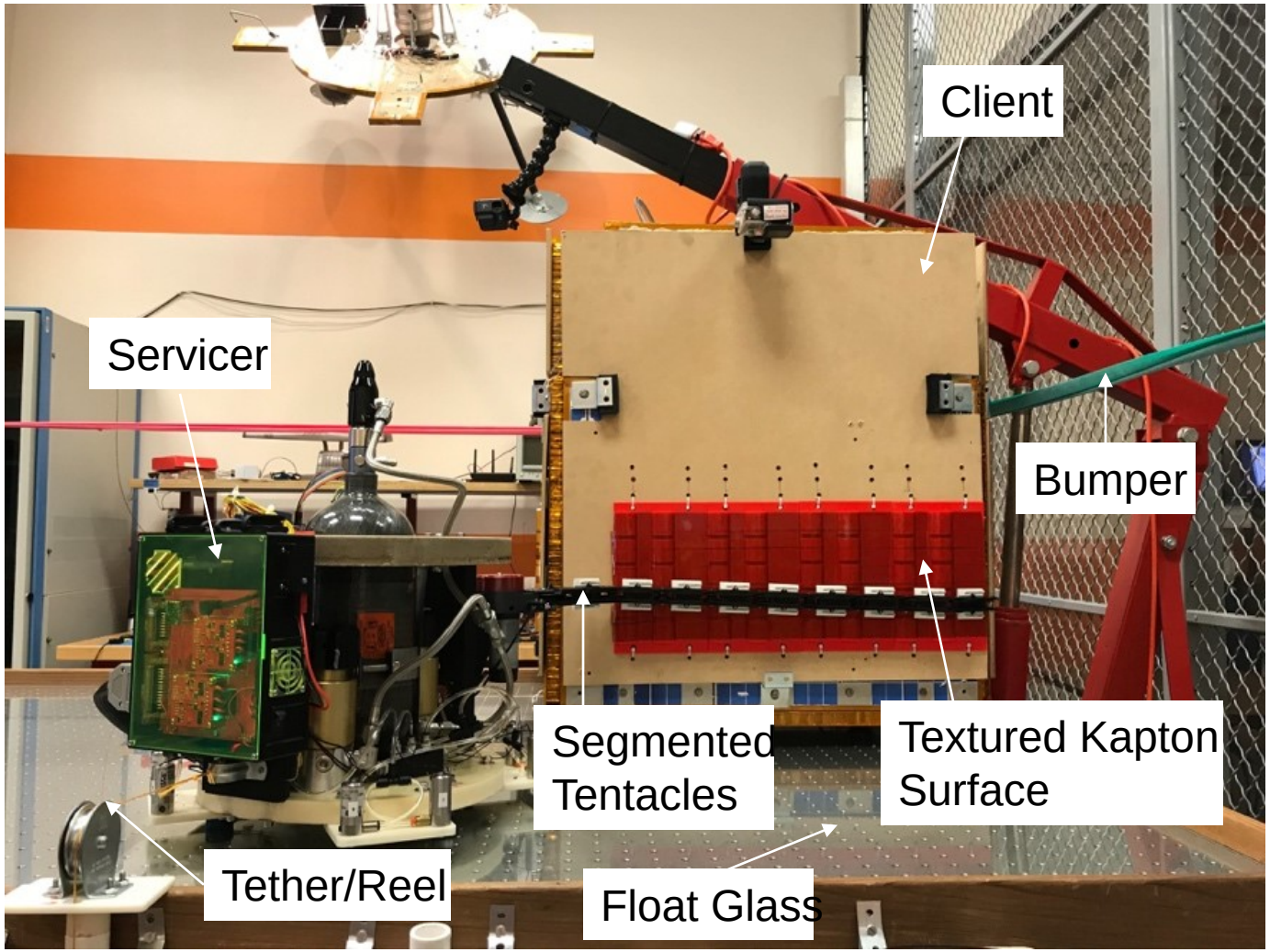






REACCH merges these elements to create a radically new system for grappling objects in Space

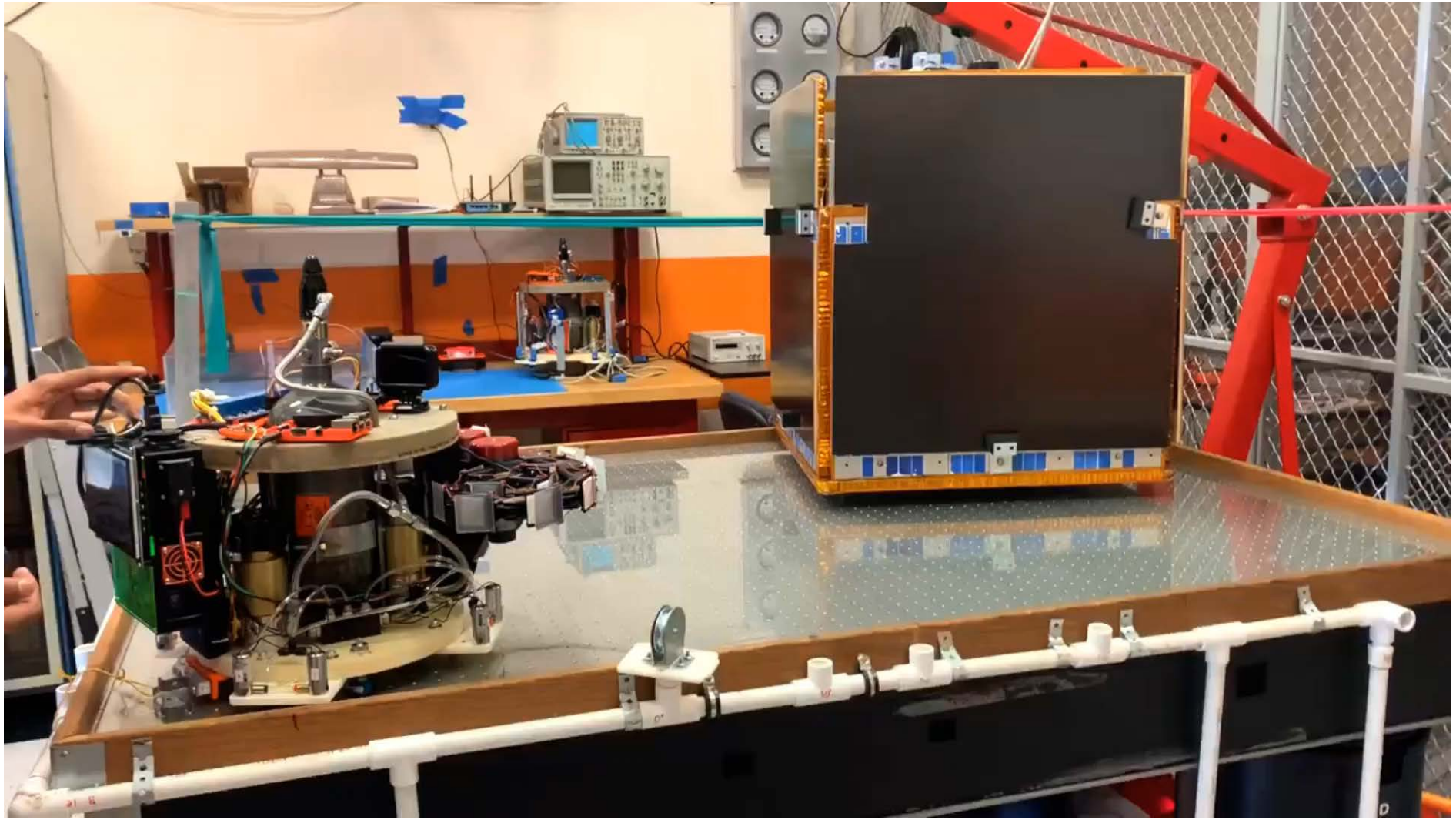
Dynamic Testing Results on 3-DOF Testbed



Smooth Surface	Rough Surfaces
Kapton	3D printed large and small humps covered in Kapton
Pyralux	
Acrylic	Solar Cells in Flat Array
Carbon Fiber	MLI Blanket

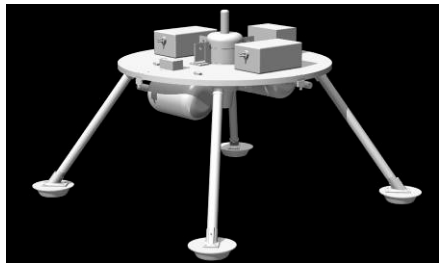
Test surfaces mimic typical space vehicle exterior material and surfaces

Demonstration – Segmented Arms



Demonstration – Continuous Arms

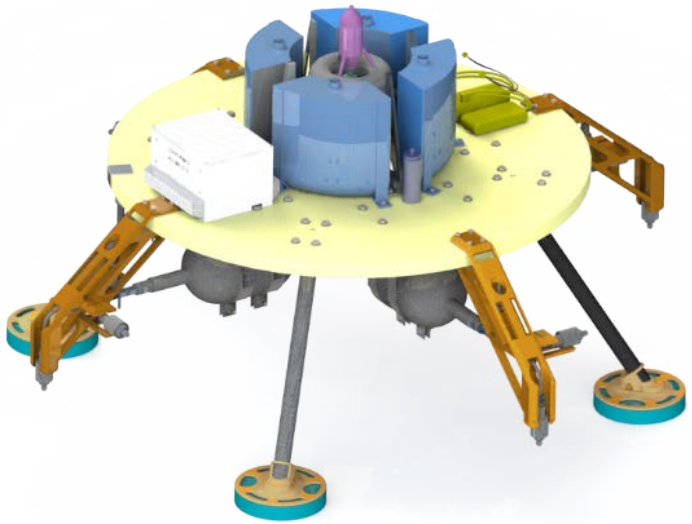
THEME to interact with a new body: LEAPFROG- Student led Innovative Lander Flight Prototype



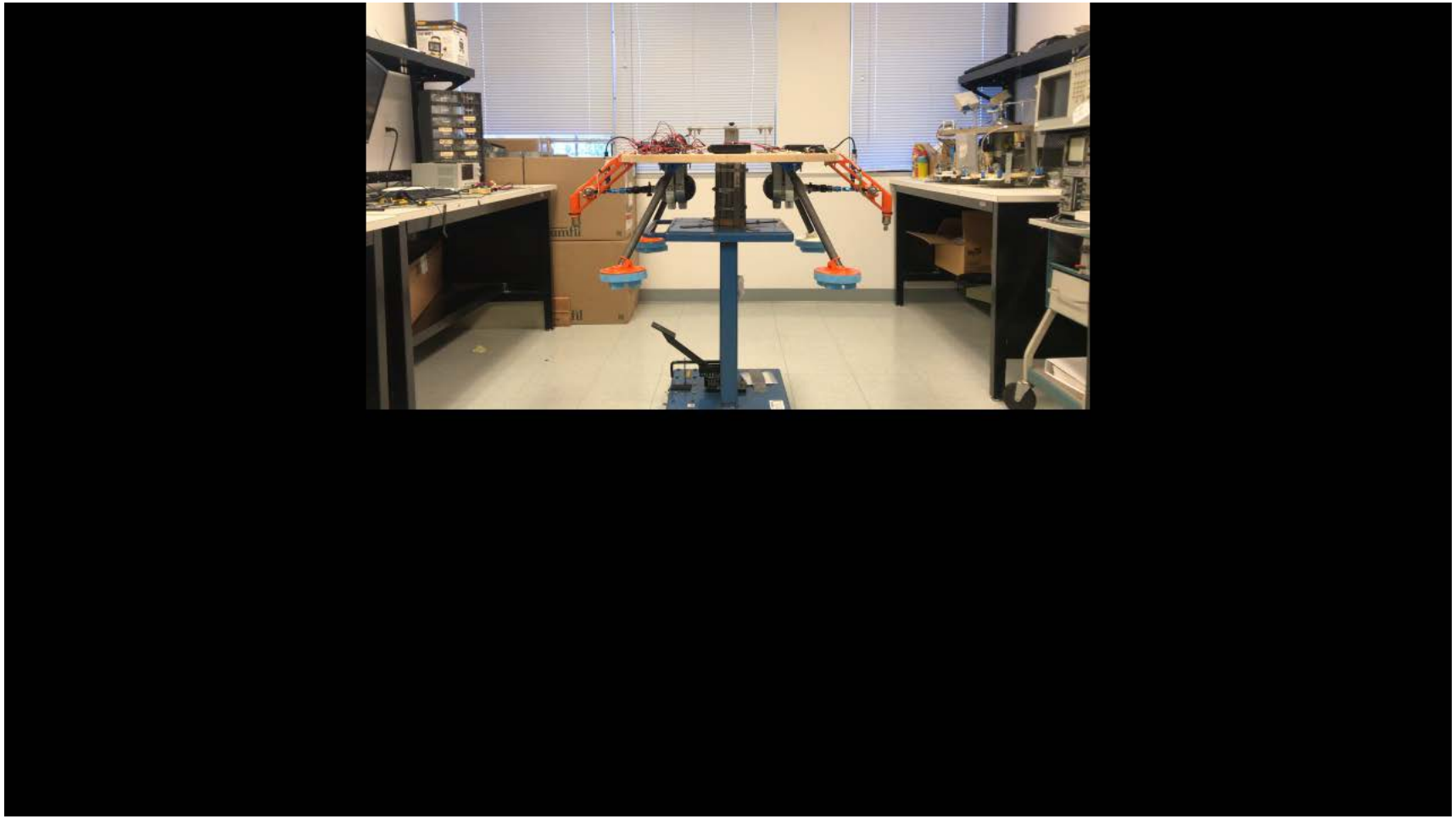
LEAPFROG

Generation 0

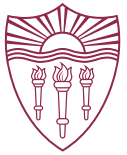
Generations of landers increase performance…



Generation 0



Currently working on a NASA effort to support a US National competition…



Generation 2…. *To be subject of another Seminar, another tease…*

Quick snapshot of upcoming Research Activities….

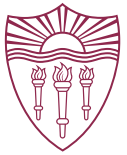
- Low Temperature Solid Rocket Propellant Investigations (ExQuadrum – Starts February 2020)
- Test of Horizon Drive-Propellantless Propulsion (LMCO – Starts February 2020)
- UScELENE: Lunar Navigation and Communications Architecture Development(NASA Pending)
- Lunar Lander Kit Based National Flight Competition (UCSD – In Work)
- “REACCH”: Octopus Gripper for Satellite Servicing, ISS Station Experiment (Exploring flight with NASA and Industry)

SERC Campus Outreach for 2020…

- **Department presentations for PI led missions and collaborative technology.**
  - **Dept of Electrical and Computer Engineering**
  - **Department of Aerospace and Mechanical**
  - **Dept of Computer Science**
  - **Dornsife-Physics…**
  - **USC Marshall…**
- **SERC Seminar Series created**
  - **Once per month to start with on Campus**
- **Spring Open House**
- **May SERC Booth at Space Tech Expo in Long Beach**
  - **All Students/Faculty invited**

- Series Planned for Spring 2020:
  - January 23rd
  - February 20th
  - March 12th
  - April 16th
  - May 7th

SERC experiences gives students unique opportunities to seed the future…



NORTHROP GRUMMAN

Relativity

NovaWurks
SPACE FOR EVERYONE

BLUE ORIGIN

MOMENTUS
SPACE

motiv
space • systems

Raytheon

OFFWORLD

Tyvak
A Terran Orbital Corporation

USC
Space Engineering
Research Center

“inspirante ad astra…”